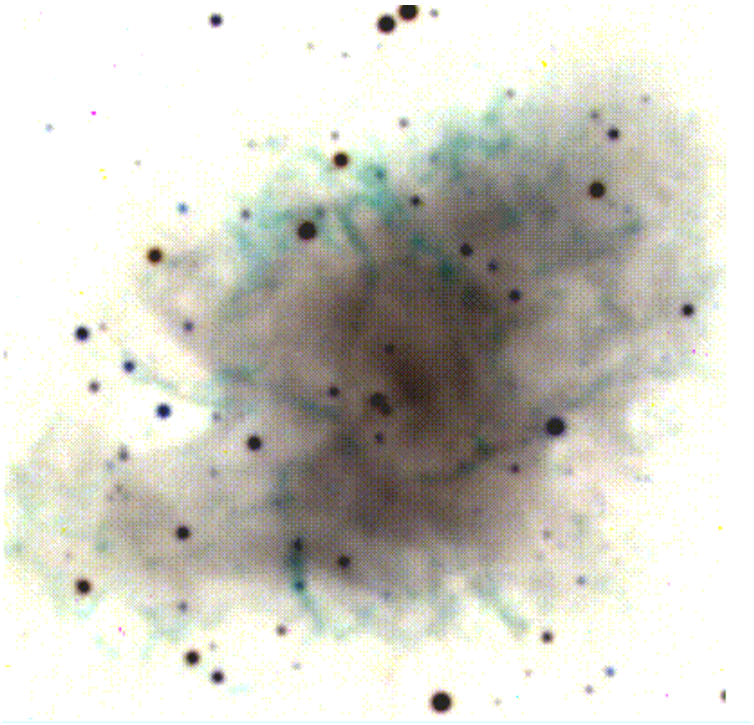
PSS

Software for the Periodic Source Search

User Guide



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Introduction

The PSS software is intended to process data of gravitational antennas to search for periodic sources.

It is based on two programming environments: MatLab and C. The first is basically oriented to interactive work, the second to batch or production work (in particular on the Beowulf farms). There are also programs developed in Matlab, then compiled by the Matlab compiler and run on the Grid environment.

The input gravitational antenna data on which the PSS software operates can be in various formats, as the **frame** (Ligo-Virgo) format, the **R87** (ROG) format, or the **sds** format (that is one of the Snag-SFC formats). The data produced at the various stages of the processing are stored in one of the Snag-SFC formats. The candidate database has a particular format.

There are some procedure to prepare data for processing. There is a basic check for timing and basic quality control. A report is created.
Then the Short FFT Database (SFDB) is created. This is done in different way depending on the antenna type. For interferometric antennas it is done for 4 bands, obtaining 4 SFDBs. For bar antennas it is done for a single band.

The SFDB contains also a collection of "very short" periodograms. It has many uses, in particular it is used for the time-frequency data quality.
From the SFDB the peak map is obtained; it is the starting point for the Hough transform.

The Hough transform (the "incoherent step" of a hierarchical procedure), that is the main part of our procedure, is normally run on a Beowulf computer farm. A Supervisor program creates and manages the set of tasks.

The Hough transform produces a huge number (from hundreds of millions to billions) of candidate sources, each defined by a starting frequency, a position in the sky and a value of the spin-down parameter. These are stored in a database and when there are independent data analysis (for different periods or for different antennas), a coincidence search is performed on them.

The "survived" candidates are then followed-up to verify their compliance with the hypothesis of being a periodic gravitational source, to refine their parameters and to compute other (like polarization).

An important part of the package is the simulation modules.

This guides ends with a report of various tests done of some parts of this package.

More information can be found on the programming guides and other documents:

- Snag2_PG
- PSS_PG
- PSS_astro_PG
- PSS_astro_UG
- PSS_Hough_PG
- Supervisor_PG

Typical pipelines

Basic

- Times are only indicative.
- Often the transfer time between computers is higher than processing time.
- After each step check and pre-analysis time should be considered (and this could be much longer).

In the table grid operations are in red, Matlab operations are in blue.

Task	Program	file in	file out	time/day	Mb/day
hrec extraction	Extract.tcsh	frame	frame	10 min	1500
frame-to-sds conversion	frame_util	hrec frame files	.sds files	10 min	1400
sds reshape	sds_reshape	.sds	.sds	15 min	1400
sfdb	crea_sfdb	.sds	.sfdb	30 min	3000
peakmap	crea_peakmap	.sfdb	.p08	15 min	450
p08 to vbl	p082vbl (by convert_peakfiles)	.p08	.vbl	30 min	300
cleaning (mask creation, new p08, new vbl)	clean_conv_peakfile (using clean_piapeak)	.vbl .p08	.vbl .p08	2 hours	750
input files creation	create_input_file	.p08	.input	3 min	450
Sky Hough map	pss_hough	.p08	.cand	4~16 hours	750~3000 (independent of time)
f/fdot Hough map	pss_...	.vbl	.cand		

(continuing)

Task	Program	file in	file out	time/day	Mb/day
single jobs candidate collection	**create_db**	**.cand**	**.cand**	**4 min**	**750**
psc type 2 db (50-1050 Hz)	**reshape_db2 (using psc_reshape_db2) or reshape_db3**	**.cand**	**242 x .cand**	**1 hour**	**750**
coincidences	**psc_coin**	**.cand**	**.cand**		

All batch procedures are submitted by **pss_batch_diary**.

Old pipelines

Up to August 2008

Task	Program	file in	file out	time/day	Mb/day
hrec extraction	Extract.tcsh	frame	frame	10 min	1500
frame-to-sds conversion	frame_util	hrec frame files	.sds files	10 min	1400
sds reshape	sds_reshape	.sds	.sds	15 min	1400
sfdb	crea_sfdb	.sds	.sfdb	30 min	3000
peakmap	crea_peakmap	.sfdb	.p05	15 min	450
p05 to vbl	piapeak2vbl or (by convert_peakfiles)	.p05	.vbl	30 min	300
cleaning (mask creation, new p05, new vbl)	clean_conv_peakfile (using clean_piapeak)	.vbl .p05	.vbl .p05	2 hours	750
input files creation	create_input_file	.p05	.input	3 min	450
Hough map	pss_hough	.p05	.cand	4~16 hours	750~3000 (independent of time)

(continuing)

Task	Program	file in	file out	time/day	Mb/day
single jobs candidate collection	create_db	.cand	.cand	4 min	750
psc type 2 db (50-1050 Hz)	reshape_db2 (using psc_reshape_db2) or reshape_db3	.cand	242 x .cand	1 hour	750
coincidences	psc_coin	.cand	.cand		

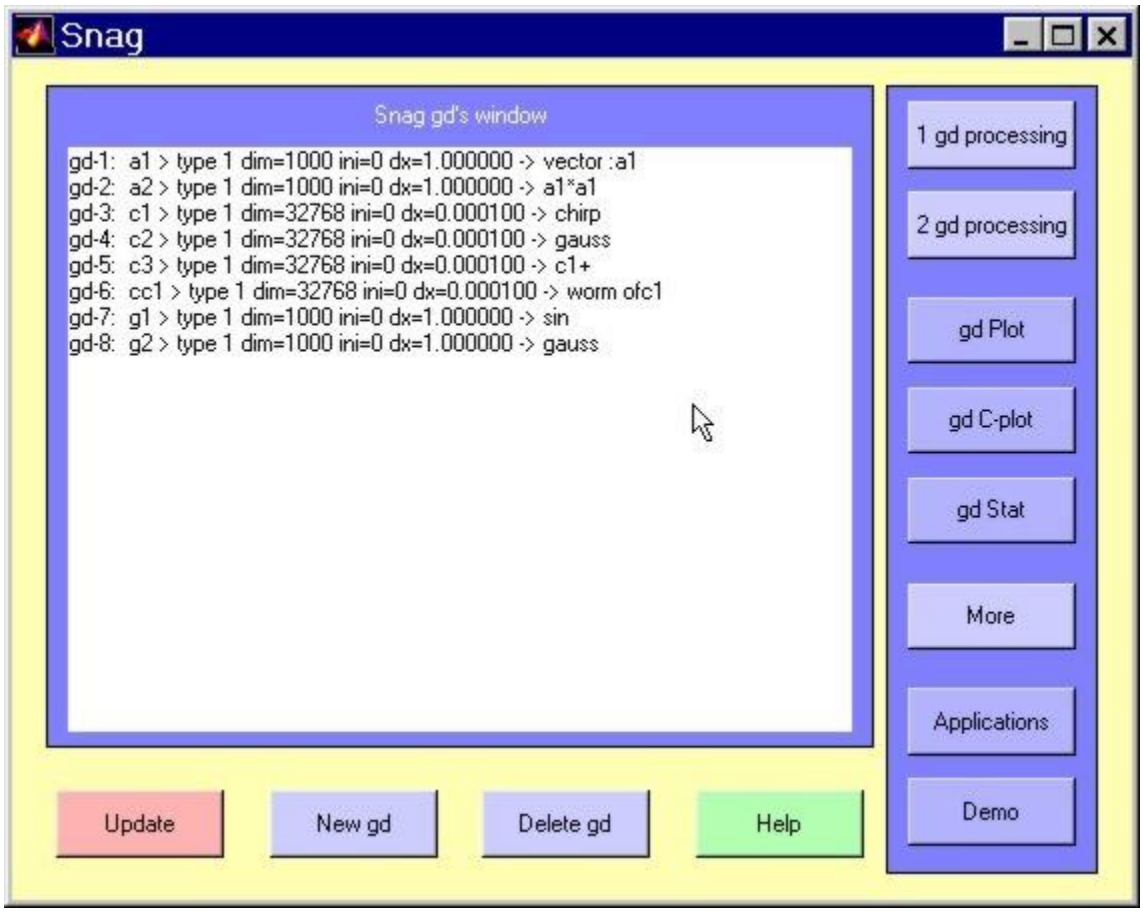
Programming environments

Matlab

For the MatLab environment the Snag toolbox is used. It contains more than 800 m functions (February 2004) and has PSS as one of the projects regarding the gravitational waves (in **snag\projects\gw\pss**). It is almost completely independent from other toolboxes.

There are two useful interactive gui programs in Snag:

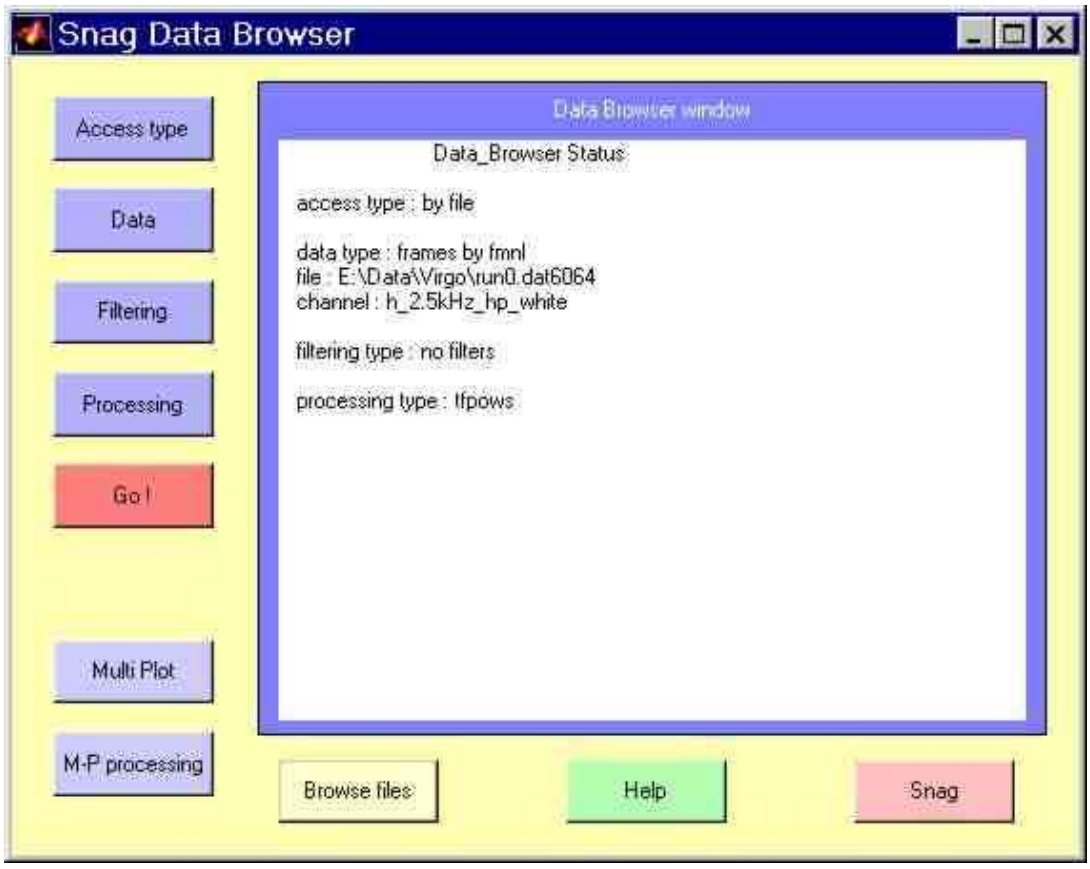
- **snag** , provides a GUI access to the **Snag** functionalities. It can be used "stand-alone", or in conjunction with the normal Matlab prompt use of **Snag**. At the Matlab command prompt, type **snag .** A window appears:


Snag
Snag gd's window
gd-1: a1 > type 1 dim=1000 ini=0 dx=1.000000 -> vector :a1
gd-2: a2 > type 1 dim=1000 ini=0 dx=1.000000 -> a1*a1
gd-3: c1 > type 1 dim=32768 ini=0 dx=0.000100 -> chirp
gd-4: c2 > type 1 dim=32768 ini=0 dx=0.000100 -> gauss
gd-5: c3 > type 1 dim=32768 ini=0 dx=0.000100 -> c1+
gd-6: cc1 > type 1 dim=32768 ini=0 dx=0.000100 -> worm ofc1
gd-7: g1 > type 1 dim=1000 ini=0 dx=1.000000 -> sin
gd-8: g2 > type 1 dim=1000 ini=0 dx=1.000000 -> gauss
1 gd processing
2 gd processing
gd Plot
gd C-plot
gd Stat
More
Applications
Demo
Update
New gd
Delete gd
Help

It has a text window, where are listed the **gd**s that have been created and some buttons.

For a more extensive description of this, see the Snag2_UG.

- **data_browser** , that is a **Snag** application (part of the **gw** project) to access and simulate gravitational antennas data. It is started by typing **data_browser** (or just **db**, if the alias is activated). This opens a window



with a text window and some buttons. The text window shows the "status" of the **DataBrowser** , as is due to the default and user's settings.

The parts that are developed in this environment are labeled **[MatLab environment].**

The gw project

Inside Snag, a gravitational wave project has been developed. An important of this project is the DataBrowser (showed in the preceding sub-section).
Other parts of this project are:

- **astro** , on astronomical computations (coordinate conversion, doppler computations)
- **time** , with a set of functions dealing with the time. Among the others:
  - conversions between mjd (modified julian date), gps and tai times
  - sidereal time
  - conversions between vectorial and string time formats
- **sources** , about gravitational sources (pulses, chirps and periodic signals)
- **pss** , specifically for the PSS software (see the sub-section)
- **pulse** , regarding pulse detection
- **gw_sim**, with data simulation
- **radpat** , for the radiation pattern and response of antennas (sidereal response of an antenna, sky coverage,…)

The pss folder

It contains about 200 functions (Feb 2007) divided in :

- **cohe** , for coherent analysis
- **hough** , for Hough transform
- **hough_exp** , containing the Hough Explorer functions
- **other** , service routines, mainly for peculiar file access
- **procedures** , batch procedures
- **psc** , periodic source candidate functions, for analysis and coincidence
- **sfdb** , short FFT database and peak map

- **sim** , simulation
- **theory** , statistical and physical theoretical analysis

C

The C environment contains a library and some module. The library contains:

- **pss_snag** : routines to operate with the snag objects (GD, DM, DS, RING, MCH)
- **pss_math** : basic mathematical routines
- **pss_serv** : service routine (among the others, vector utilities, string utilities, bit utilities, interactive utilities, "simple file" management
- **pss_gw** : physical parameters management
- **pss_astro** : astronomical routines
- **pss_frame** : routines for frame format access
- **pss_r87** : routines for r87 format access
- **pss_sfc** : routines for the sfc file formats management
- **pss_snf** : routines for snf format management (partially obsolete)

The other modules are:

- **pss_bench** : for computer benchmarks
- **pss_math** : basic mathematical routines
- **pss_sfdb** : for short FFT data base and peak maps creation and management
- **pss_hough** : for hough transform
- **pss_cohe** : for the coherent step of the hierarchical search
- **pss_ss** : Hough tasks management and supervision

The parts that are developed in this environment are labeled **[C environment].**

SFC formats

Basics

The basic feature of the file formats here collected is the ease of access to the data.

The "ease of access" means:

- the software to access the data consists in a few lines of basic code
- the data can be accessed easily by any environment and language
- the byte level structure is immediately intelligible
- no unneeded information is present
- the number of pointers and structures is minimized
- the structure fits the needs
- the access is fast and, possibly, direct
- the need for generality is tempered by the need for easiness.

The collection is composed by:

- **sds**, *simple data stream* format, for finite or "infinite" number of equispaced samples, in one or more channels, all with the same sampling time
- **sbl**, *simple block* data format, in a more general case; a block can contain one or more data types: any block have the same structure (i.e. the sequence and the format of the channels is the same) and the same length (i.e. the number of data in a block for a certain channel, is always the same).
- **vbl**, *varying length block* data format, where the structure of all the blocks is the same, but the length can be different.
- **gbl**, *general block* data format: it is not a format, but practically a sequence of superblocks, each following one of the preceding formats; it is a repository of data, not necessary well structured for an effective analysis, but good for storage, exchange, etc..

A set of files can be:

- **internally collected,** i.e. ordered serially or in parallel using the internal file pointers (for example subsequent data files, or to put together different sampling time channels)
- **externally collected**, i.e. logically linked by a collection script file, as it happens for internal collecting
- **embedded** in a single file, with a toc at the beginning or at the end. This is the case of the gbl files.

A file can be **wrapped** by adding one or more external headers (for example describing the computer which wrote the file).

The SFC data formats are presented in the Snag2 Programming Guide (Snag2_PG.pdf).

Compressed data formats

These formats are not compulsory (they are not used for the first development phase).

LogX format

This is a format that can describe a real number (float) with little more than 16, 8, 4, 2 or 1 bits. X indicates this number of bits.
It uses normally a logarithmic coding, but can use also linear coding and, in particular cases, the normal floating 32-bit format. In the case that all the data to be coded are equal, only one data is archived (plus the stat variable).
It best applies to sets of homogeneous numbers.
Let us divide the data in sets that are enough homogeneous, as a continuous stretch of sampled data. The conversion procedure computes the minimum and the maximum of the set and the minimum and the maximum of the absolute values of the set, checks if the numbers are all positive or negative, or if are all equal, then computes the better way to describe them as a power of a certain base multiplied by a constant (plus a sign). So, any **non-zero** number of the set is represented by

$$\mathbf{x_i = S_i * m * b^{E}_{i}}$$

or, if all the number of the set have the same sign,

$$\mathbf{x_i = S * m * b^{E}_{i}}$$

where

- $\mathbf{S_i}$ is the sign (one bit)
- **m** is the minimum absolute value of the numbers in the set
- **b** is the base, computed from the minimum and the maximum absolute value of the numbers of the set
- $\mathbf{E_i}$ is the (positive) exponent (15 or 16 bits for Log16, 7 or 8 bits for Log8, and so on).

The coded datum 0 always codes the uncoded value 0 (also if such a value doesn't exist).

m, **b**, and a control variable that says if all the number are positive, negative or mixed are stored in a header. The data bits contain **S** and **E** or only **E**.
The minimum and maximum values can be imposed externally, as saturation values.

In case of mixed sign data, in order to have automatic computation of **m** and **b**, an **epsval** (a minimum non-zero absolute value) should be defined. If this is put to 0, this value is substituted with the minimum non-zero absolute datum.

The zero, in the case of mixed sign data, is coded as "111…11", while "000…00" is the code for the number m ("1000…00" is –m, "0111…11" is the maximum value and "111…110" the minimum).

The mean percentage error in the case of a gaussian white sequence is, in the case of Log16, better then 10^{-4} .

Also a linear coding is possible:

$$\mathbf{x_i = m + b * E_i}$$

Also in this case, the coded datum 0 always codes the uncoded value 0 (also if such a value doesn't exist).
In case of linear coding, if the data are "mixed sign" (really or imposed) and X is 8 or 16, E is a signed integer, otherwise it is an unsigned integer: normally, in the first case, m is 0.

In case of data dimension **X** less than 8 (4, 2 or 1: the sub-byte coding), the logarithmic format is substituted by a look-up table format. In such case, a look-up table of $\mathbf{(2^X - 1)}$ fixed thresholds $\mathbf{t_k}$ $\mathbf{(0<k<2^X - 2)}$, in ascending order, must be supplied. Data $\mathbf{< t_0}$ are coded as 0, data between $\mathbf{t_{k-1}}$ and $\mathbf{t_k}$ are coded as k and data greater than the last threshold are coded as 11..1 . In the case of linear sub-byte coding, the coded data are unsigned.

Here is a summary of the LogX format:

Number of bits	32	16	8	4	2	1	0
Coding	float	2 linear 2 logarithmic	2 linear 2 logarithmic	linear look-up	linear look-up	linear look-up	constant

Logarithmic coding can be done using X or X-1 bits for the exponent, depending if the last bit is used for the sign. Linear coding can be (for X = 8 or 16) signed or unsigned integer coded.
Linear and logarithmic coding can be adaptive.
So, totally, we have 16 different LogX formats (7 linear, 4 logarithmic, 3 look-up table, 1 float and 1 constant float), 11 of which can be adaptive.

Sparse vector formats

Sparse vector is a vector where most of the elements are 0. We call "density" the percentage of non-zero elements. Sparse matrixes are formed by sparse vectors.
Sometimes (binary matrices) the non-zero elements are all ones and sometimes they are also aggregated. In this last case the binary derivative (0 if no variation, 1 if a variation is present) is often a sparse vector with lower density value.
We represent sparse vectors with the "run-of-0 coding". It consists in giving just the number of subsequent zeros, followed by the value of the non-zero element. In the case of binary vectors, the value of the non-zero element is not reported.

Examples:

{1.2 0 0 0 0 0 3.2 0 0 0 0 0 0 2.3 0 0 0 0 0 0 0 0 3.0 0 0 0 2.}

coded as {0 1.2 5 3.2 6 2.3 8 3.0 3 2.}

binary case:
{0 0 0 1 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 1 1 0 0 0}

coded as {3 6 8 0 3}

aggregate binary case:

{1 1 1 0 0 0 0 0 0 0 0 1 1 1 1 0 0 0 0 0 0 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 1 1 1}

binary derived as

{1 0 0 1 0 0 0 0 0 0 0 1 0 0 0 1 0 0 0 0 0 1 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 1 0 0}

coded as

{0 2 7 3 5 4 9 2}.

In practice the number of subsequent zeroes is expressed by an unsigned integer variable with b = 4, 8, 16 or 32 bits; one is added to the coded values, in such a way that the value 0 is an escape character used if more than 2^n-2 zeroes should be represented; in such case the datum is put in a side array of uint32.

In practice, there are 5 different cases:

sparse, non-binary	⇒	the 0-runs and the non-zero elements
sparse, binary	⇒	only the 0-runs of the sequence
sparse, derived binary	⇒	only the 0-runs of the derived sequence
non-sparse, non-binary	⇒	normal vector (a float per element)
non-sparse, binary	⇒	one bit per element

PSS SFC files

The PSS (Periodic Source Search) project uses many different types of data to be stored. Namely:

- **h-reconstructed sampled data, raw and purged**
- **Short FFT data bases**
- **Peak maps**
- **Hough maps**
- **PS candidates**
- **Events**

Each of these has a peculiar type of SFC.

- **h-reconstructed sampled data, raw and purged**

  This type of data are normally stored with simple SDS.

- **Short FFT data bases**

  The data are stored in a SBL file.

  In the user field there are other information like:
  - [I] **FFT length** (number of samples of the time series)
  - [I] **Interlacing size** (number of interlaced samples)
  - [D] **sampling time** of the time series

  [S] **window** (used on the time series)

  The blocks contain:

  - one half of the FFT of purged sampled data
  - one short power spectrum
  - one one-minute mean vector
  - a set of parameters as:
    - [I] **number of added zeros** (for errors, holes or over-resolution)
    - [D] **time stamp** of the first time datum (**mjd**)
    - [D] **time stamp** of the first time datum (**gps time**)
    - [D] **fraction** of the FFT time that was padded with zeros
    - [D] **velocity and position of the detector** at time of the middle datum[1] (vx_eq, vy_eq, vz_eq, px_eq, py_eq, pz_eq: coordinates in Equatorial reference frame, fraction of c)

[1] Middle datum means the $L_{FFT} / 2 + 1$ datum.

- [D] **position of the detector** at time the middle datum (x_eq, y_eq, z_eq: coordinates in Equatorial reference frame, in meters of SSB)

- **Peak maps**

The data are stored in a VBL file. The header is similar to that of the SFDB, but a peak vector takes the place of the FFT. The format of the peak vector is a sparse binary vector, so the real length of each block is not constant.

There are two versions of the vbl peak maps, derived from the non-standard format p05 and p08:

- **up to August 2008**:
  There are 3 channels:

  - the velocity of the vector (Cartesian, in the Ecliptic reference frame, fraction of c)
  - the frequency bins of the peaks (integer)
  - the equalized peak values.

- **starting from August 2008**:
  There are 5 channels:

  - the velocity of the vector (Cartesian, in the Ecliptic reference frame, fraction of c)
  - the short spectrum
  - the index of the peaks array (for direct access to PEAKBIN)
  - the frequency bins of the peaks (integer; **can be negative for vetoed peaks**)
  - the equalized peak values.

  The channels have the following parameters:

CH	name	lenx	dx	type
1	DETV	3	-	double
2	SHORTSP	length of short spectrum	sh.sp. frequency step	float
3	INDEX	length of short spectrum	sh.sp. frequency step	int
4	PEAKBIN	length of half FFT	FFT. frequency step	int
5	PEAKCR	-	-	float

- **starting from November 2010**:
  There are 6 channels:

  - the velocity of the vector (Cartesian, in the Ecliptic reference frame, fraction of c)
  - the short spectrum
  - the index of the peaks array (for direct access to PEAKBIN)
  - the frequency bins of the peaks (integer; **can be negative for vetoed peaks**)
  - the equalized peak values.
  - the mean for the peaks

The channels have the following parameters:

CH	name	lenx	dx	type
1	DETV	3	-	double
2	SHORTSP	length of short spectrum	sh.sp. frequency step	float
3	INDEX	length of short spectrum	sh.sp. frequency step	int
4	PEAKBIN	length of half FFT	FFT. frequency step	int
5	PEAKCR	-	-	float
6	PEAKMEAN	-	-	float

- **Hough maps**

  The data are stored in SBL or VBL files. The parameter to be stored in each block (containing a single Hough map) are:

  - the **length** of the record
  - the **parameters** of the hough map (**amin, da, na, dmin, da, nd**)
  - the **spin down parameters** (**nspin, spin1,spin2**,…)
  - the **number of used periodograms** and the type (**interlaced, windowed,…)**
  - the **initial times and length** of each periodogram
  - the **type and the parameters** of the **threshold**

- **PS candidates and Events**

  - These data could be stored in an SDS file, with many channels, but, for the necessity of easy random access needed for such data bases, a peculiar format will be used.

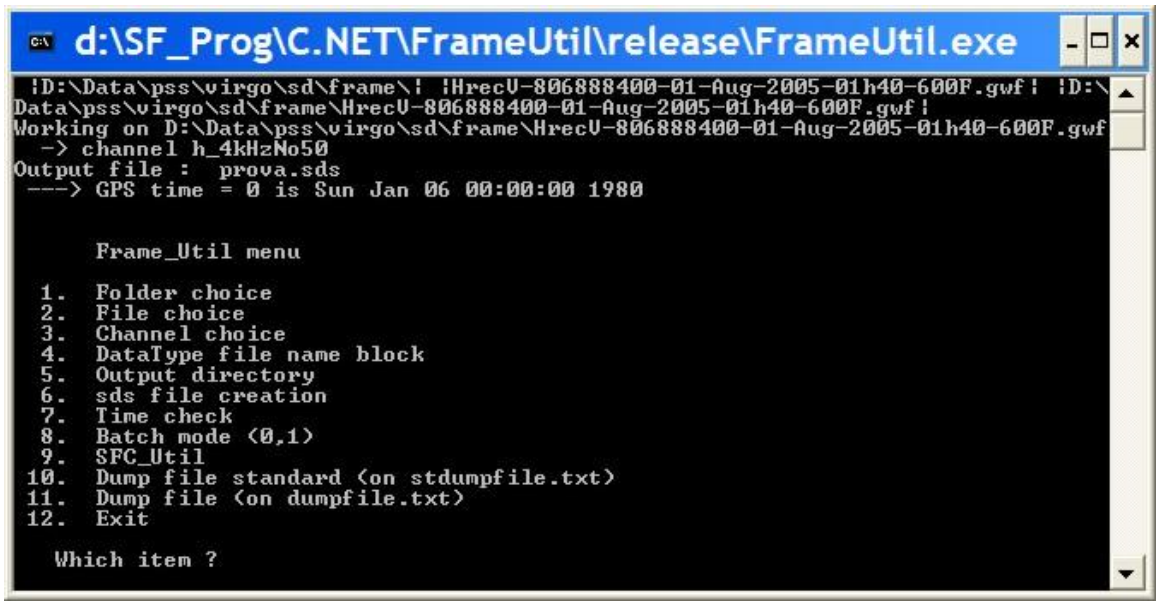
Data preparation

Format change

[C environment]

In order to use some Snag features in a more proficient way, the frame format data must be must be converted in the sds format. This can be accomplished by the interactive program **FrameUtil.exe**. It can be run in two ways: interactive or batch:

- **Interactive (can be used also in batch mode in some systems)**



Very useful are the two dump file facilities, that give a resume of all the frames.

The program can be used also in batch, creating a batch file as this:

8	**!** ask batch mode
1	**!** sets batch mode
1	**!** ask item choice of the directory
/home/federica/hrec-v2/	**!** input directory
3	**!** ask channel choice
dL_20kHz	**!** channel
4	**!** ask item DataType file name block
hrec	**!** the block
5	**!** ask output directory
/home/federica/sds/	**!** output directory
2	**!** ask item File choice
hrec-710517600-3600.gwf	**!** the file
6	**!** creates the sds file

```
2                          ! ask item File choice
hrec-710521200-3600.gwf    !
6                          ! creates the sds file
2                          ! ask item File choice
hrec-710524800-3600.gwf    !
6                          ! creates the sds file
12                         ! exit
```

To create easily the batch file, create a list of the files to be converted and then edit it. In Windows the command is

dir /b > list.txt

and can be issued with the command file **to_list.bat** ; it creates a file list.txt, to be edited to create the batch command file.

To start the program a batch command can be created containing something like

D:\SF_Prog\C.NET\FrameUtil\Release\frameutil < batchwork.txt > out.txt

- ## Simple batch mode

Alternatively the program can be run with the argument of a text file that contains the configuration and the file names, in this way:

> frameutil batch.txt

The text file (any name is possible) has the following format:

```
folder in          example: D:\Data\pss\virgo\sd\frame\
folder out         example: D:\Data\pss\virgo\sd\sds\
channel            example: h_4kHz
antenna acronym    example: VIR
data type          example: hrec
frame file1        example: HrecV-806888400-01-Aug-2005-01h40-600F.gwf
frame file2
frame file3
   ...
```

If we have a set of sds files, we can "concatenate" them, i.e. put in each of them the correct values for filspre and filspost, so the data can be seen as a continuous stream, and one can access at any of them pointing to any file of the chain (also not containing the given datum). This concatenation is performed, for example, by the function

- **sds_concatenate(folder,filelist)** , where **folder** is the folder containing the files and **filelist** a file containing the file list (similar to the above list.txt) in the correct order. **Be sure that the files in the list are in the correct order !**

A more complex operation on a set of sds files is performed by

- **sds_reshape(listin,maxndat,folderin,folderout)** , that constructs a new set of sds files with different maximum length and concatenates them. In this way a more efficient data set is built.

  - **listin** is a file containing the file list (similar to the above list.txt) **in the correct order**
  - maxndat is the maximum number of data for a channel
  - **folderin** and **folderout** are the folders containing the input and output data

When all the files of a run are produced and concatenated (possibly with sds_reshape), they should be checked by

- **check_sds_conc(outfile)** , that analyzes the set of files, producing a report in outfile (or on the screen, if outfile is absent). Here is an example of one of these reports (c5-data.check):

```
VIR_hrec_20041203_004502_.sds 03-Dec-2004 00:45:02.000000  duration: 3790.000000 s  chs:
h_4kHz  - err = 0.000000
    1598.000000 s --> HOLE at 03-Dec-2004 01:48:12.000000
VIR_hrec_20041203_021450_.sds 03-Dec-2004 02:14:50.000000  duration: 12500.000000 s  chs:
h_4kHz  - err = 0.000000
VIR_hrec_20041203_054310_.sds 03-Dec-2004 05:43:10.000000  duration: 1949.000000 s  chs:
h_4kHz  - err = 0.000000
    50.000000 s --> HOLE at 03-Dec-2004 06:15:39.000000
VIR_hrec_20041203_061629_.sds 03-Dec-2004 06:16:29.000000  duration: 4490.000000 s  chs:
h_4kHz  - err = 0.000000
    13172.000000 s --> HOLE at 03-Dec-2004 07:31:19.000000
VIR_hrec_20041203_111051_.sds 03-Dec-2004 11:10:51.000000  duration: 881.000000 s  chs:
h_4kHz  - err = 0.000000
    57.000000 s --> HOLE at 03-Dec-2004 11:25:32.000000
VIR_hrec_20041203_112629_.sds 03-Dec-2004 11:26:29.000000  duration: 803.000000 s  chs:
h_4kHz  - err = 0.000000
    23392.000000 s --> HOLE at 03-Dec-2004 11:39:52.000000
VIR_hrec_20041203_180944_.sds 03-Dec-2004 18:09:44.000000  duration: 776.000000 s  chs:
h_4kHz  - err = 0.000000
    106.000000 s --> HOLE at 03-Dec-2004 18:22:40.000000
VIR_hrec_20041203_182426_.sds 03-Dec-2004 18:24:26.000000  duration: 9454.000000 s  chs:
h_4kHz  - err = 0.000000
    51.000000 s --> HOLE at 03-Dec-2004 21:02:00.000000
VIR_hrec_20041203_210251_.sds 03-Dec-2004 21:02:51.000000  duration: 15.000000 s  chs:
h_4kHz  - err = 0.000000
    42.000000 s --> HOLE at 03-Dec-2004 21:03:06.000000

    ..................................................


           Summary

 133 files start: 03-Dec-2004 00:45:02.000000  end: 06-Dec-2004 14:28:21.000000   Tobs =
3.571748 days

   129 holes  of total duration 141025.000000 s     percentage = 0.456985
```

Data selection

[MatLab environment]

Basic sds operations

If the sampled data are in the sds format, it is easy to perform a variety of tasks. Here we will speak of higher level tasks (lower levels are discussed in the programming guides). Among the others, of particular interest for the PSS :

- **sfc_=sfc_open(file)** , that outputs the **sfc** structure of the file

- **[chss,ndatatot,fsamp,t0,t0gps]=sds_getchinfo(file)** , that shows the UTC time and outputs channels (in a cell array), the total number of data, the sampling frequency and the initial time both in MJD (modified julian date) and gps.

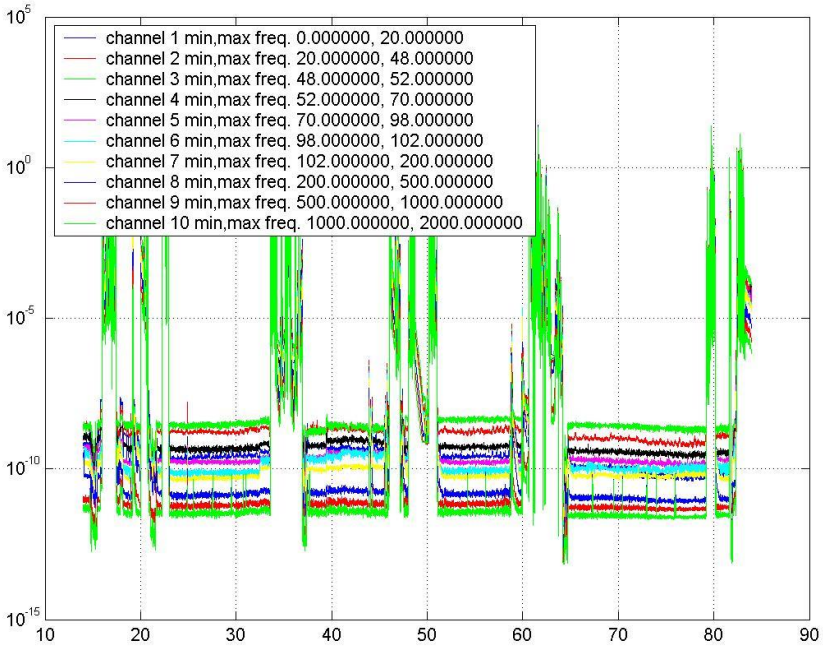
- **g=sds2gd_selt(file,chn,t)** , creates a gd from file, channel number chn and t = [initial time, duration]; if the parameters are not present, asks interactively.

- **sds_spmean(frbands,file,chn,fftlen,nmax)** , creates an sds file, named **psmean.sds**, containing the spectral means for many different bands. **frbands** is an Nx2 matrix containing the bands; if it is not present, it can be input as a text file like, for example,

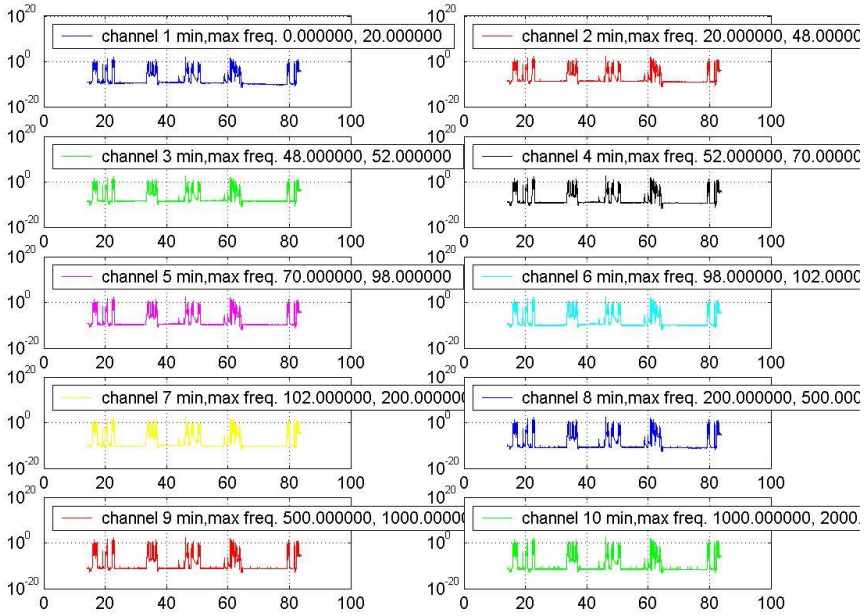
  0 20
  20 48
  48 52
  52 70
  70 98
  98 102
  102 200
  200 500
  500 1000
  1000 2000

  file and **chn** are the file and the channel number, **fftlen** is the length of the FFT and **nmax** the maximum number of output data (put a big number and all the concatenated files will be analyzed).

- **m=sds2mp(file,t)** , creates an **mp** (multi-plot structure) from an sds file (the command can be issued without parameter and asks interactively). For example, it can be applied to the spectral mean sds file created by **sds_spmean**. The mp structure can be showed by **mp_plot(m,3)** (m is the mp and 3 means log y), obtaining (on E4 data of the CIF)



or else (among other choices)


channel 1 min,max freq. 0.000000, 20.000000
channel 2 min,max freq. 20.000000, 48.00000
channel 3 min,max freq. 48.000000, 52.000000
channel 4 min,max freq. 52.000000, 70.00000
channel 5 min,max freq. 70.000000, 98.000000
channel 6 min,max freq. 98.000000, 102.000
channel 7 min,max freq. 102.000000, 200.00000
channel 8 min,max freq. 200.000000, 500.00
channel 9 min,max freq. 500.000000, 1000.0000
channel 10 min,max freq. 1000.000000, 2000.

The abscissa is in hours from the 0 hours of the first day.

- **crea_ps(sdsfile,chn,lfft,red)** , creates an **sbl** file containing power spectra of data (similar to that produced for the **sfdb**), from channel number **chn**, a "big FFT length" **lfft** and a length of the power spectra **lfft/red**.

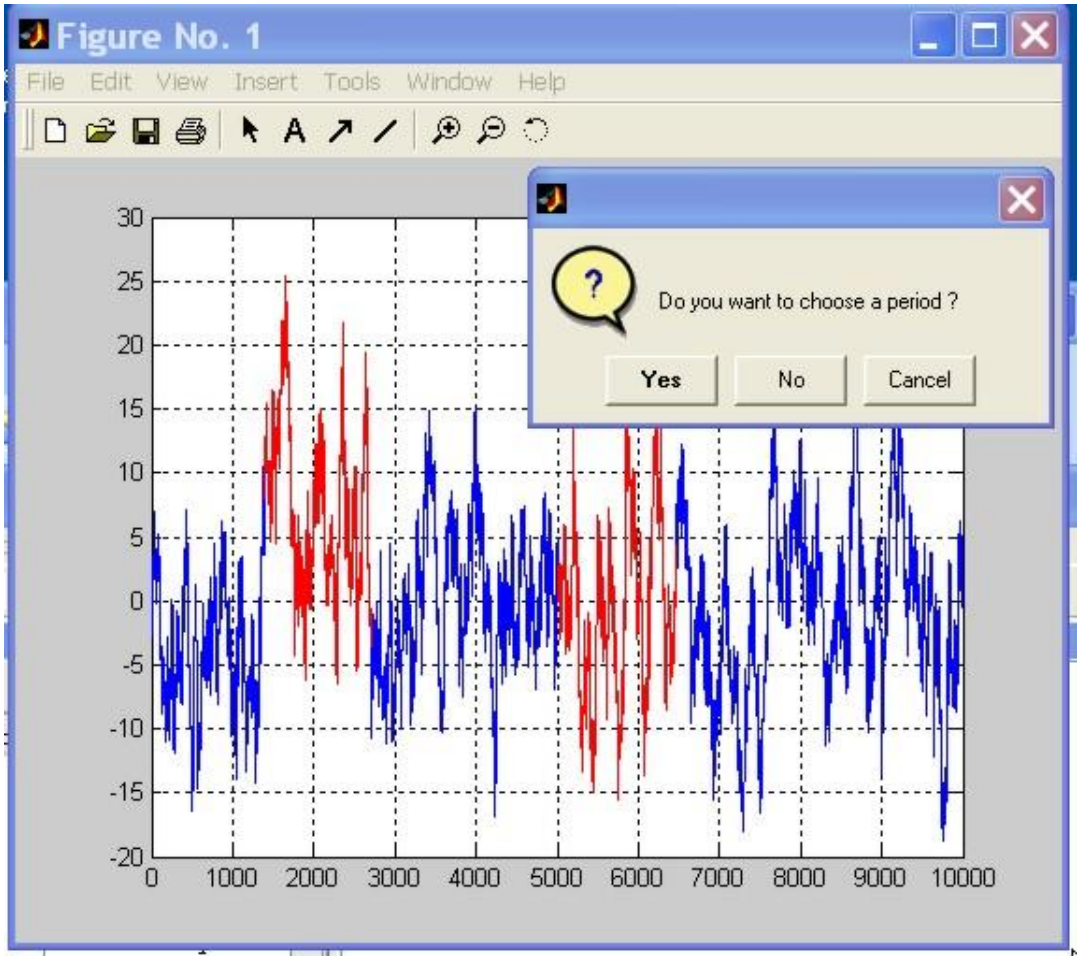
Choice of periods

[MatLab environment]

The choice of the periods on which the SFDB should be created (and then are to be analyzed) can be done by the use of the Virgo data quality information and of the basic instruments like those shown in the preceding section.

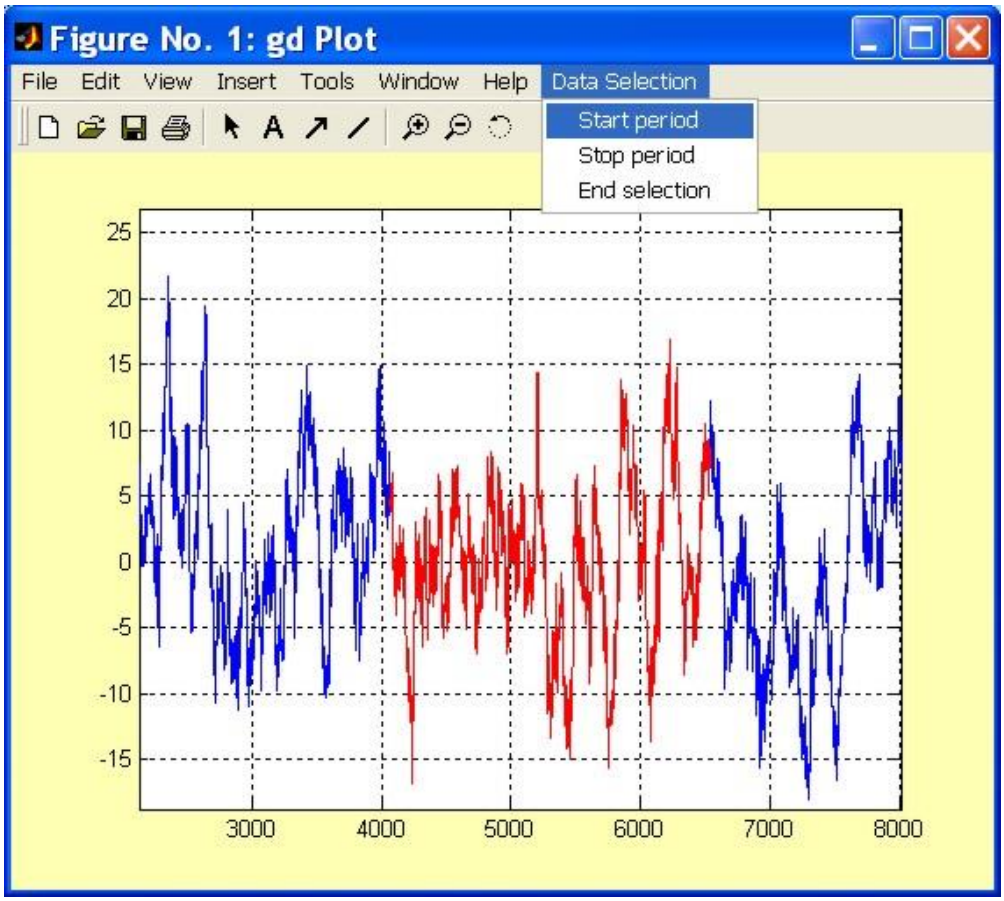
In Snag there are some useful interactive functions that helps in choosing prtiods:

- **xx=sel_absc(typ,y,x,file)** , the easyest one, where **typ** (0,1,2,3) indicates the type of plot (simple, logx, logy, logxy), **y** is a gd or an array, **x** is simply 0 (if y is a gd) or the abscissa array, **file** (if present) is the file to put the output, i.e. the starting and ending points of the chosen periods; xx is an (n,2) array with the bounds of the chosen periods. This program is very simple to use: you can directly choose the start and stop abscissa of as many periods you want; when you chose the stop point, the chosen period is colored in red and you are prompted if you choose another period

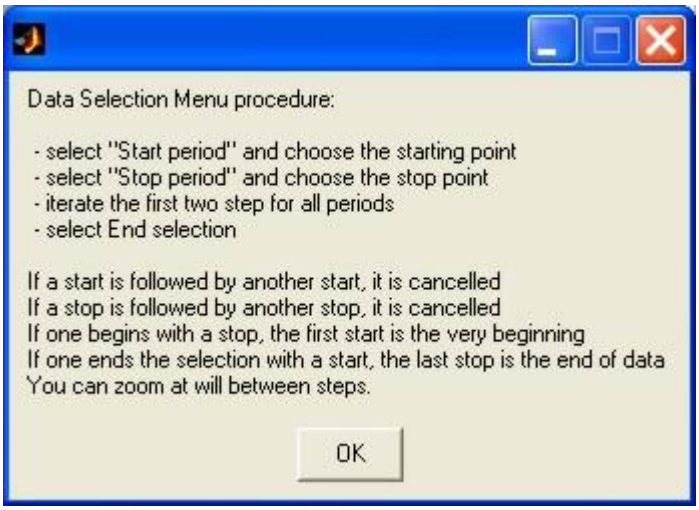


The problem with this function is that it is not possible to zoom the plot for more precise choice.

- **sel_absc_hp(typ,y,x)** , permits the use of the zoom and so an high precision choice. It uses global variables (**ini9399**, **end9399**, **n9399** as the beginning times, ending times and number of periods); The data of the periods are put in a file named **fil9399.txt**. The input variables **typ**, **y** and **x** have the same use of the function **sel_absc**.



There are some easy rules that appear at beginning:


Data Selection Menu procedure:
- select "Start period" and choose the starting point
- select "Stop period" and choose the stop point
- iterate the first two step for all periods
- select End selection
If a start is followed by another start, it is cancelled
If a stop is followed by another stop, it is cancelled
If one begins with a stop, the first start is the very beginning
If one ends the selection with a start, the last stop is the end of data
You can zoom at will between steps.
OK

Search for events

[MatLab environment]

Filtering in a ds framework

The ev-ew structures

The event management is done by the use of the **ev-ew** Snag structure (see the programming guide Snag2_PG.pdf). An event is defined by a set of parameters, like

- the (starting) time of the event (in days, normally mjd)
- the time of the maximum (in days, normally mjd)
- the channel
- the amplitude
- the critical ratio
- the length (in seconds)
- …

The difference between the **ev** and **ew** structures is that the first describes a single event (so a set of events is an array of structures), the second describes a set of events. The **ew** structure is normally more efficient, but the **ev** structure is more rich (it can contain also the shape of the event). The two function **ew2ev** and **ev2ew** transform one type in the other (losing the shape, if present).
A set of events is associated to a channel structure that describes the channels that produced the events, constituting a new event/channel structure **evch**.

There is a number of auxiliary functions to manage events:

- **chstr=crea_chstr(nch)** , creates a channel structure for events; nch is the number of channels
- **evch=crea_ev(n,chstr,tobs)** , creates an event-channel structure, simulating n events in the time span tobs, and with the channel structure chstr
- **evch=crea_evch(chstr,evstr)** , creates an event-channel structure, from a channel structure and an event structure
- [**fil,dir,fid]=save_ech(ch,direv,fil,mode,capt)** , save a channel structure in an ascii file that can be edited; ch is the channel structure, direv and fil are the default folder and file, mode is 0 for standard, 1 for the full evch, capt is the caption
- **[fil,dir]=save_ev(ev,direv,fil,mode,fid,capt)** , save an event structure in an ascii file that can be edited; ev is the event structure, direv and fil are the default

folder and file, mode is 0 for standard, 1 for the full evch, fid is the file identifier (or 0), capt is the caption

- **save_evch(evch)** , saves an evch structure in Matlab format
- **load_evch** , interactively loads an evch structure in Matlab format
- **eo=sort_ev(ei)** , time sorts an event structure
- **out=ev_sel(in,ch,t,a,l)** , selects events on the basis of the channel, time occurrence, amplitude and length.
  - **in** and **out** are the input and output **evch** structure,
  - **ch** , if it is an array, it is the probability selection of different channels (if < 0, the channel disappear), otherwise is not used;
  - **t**, **a**, **l** , if it is an array of length 2, defines the interval of acceptance; if the first element is greater than the second, they defines the interval of rejection
- **chstr=stat_ev(evch)** , statistics for events
- **dd=ev_dens(evch,selch,dt,n)** , event densities;
  - **evch** event/channel structure
  - **selch** selection array for the channels (0 exclude, 1 include)
  - **dt** time interval
  - **n** number of time intervals
- **ev_plot(evch,type**) , plots events. type is:

0. simple
1. amplitude colored
2. length colored
3. both
4. stem3 amplitude
5. stem3 length
6. stem3 both

Coincidences

To study coincidences between events a set of functions is provided:

- **[dcp,ini3,len3,dens] = ev_coin(evch,selch,dt,n,type,coinfun)** , creates a delay coincidence plot (**dcp**) and finds coincident events (**ini3, len3** are the initial times and lengths, **dens** is the event density, if used). In input:
  - **evch** is an event/channel structure

- **selch** is a selection array, with the dimension of the number of channels, that defines which channels are to be put in coincidence: every channels can be
  - 0 excluded
  - 1 put in the first group
  - 2 put in the second group
  - 3 put in both
- **dt** is the time resolution (s)
- **n** is the number of delays for each side
- **type** an array indicating the coincidence type:

  type(1) : 1 only event maxima
  2 whole length coincidences

  type(2) : 1 normal
  2 density normalized

  type(3) : density time scale (s) for density normalization
- **coinfun** if exists, external coincidence function is enabled. The coincidence function is > 0 if the events are "compatible"; the inputs are (len1,len2,amp1,amp2), that are the lengths and amplitudes for the two coincident event.

It produces the plot of the delay coincidences and its histogram.

- **[dcp,in3,len3]=vec_coin(in1,len1,in2,len2,dt,n,coinfun,a1,a2)** , is one of the coincidence engines used inside **ev_coin**. It considers the length of the events
- **[dcp,in3]=vec_coin_nolen(in1,in2,dt,n,coinfun,a1,a2)** , is one of the coincidence engines used inside **ev_coin**. It considers the length of the events as **dt.**
- **ch=ev_corr(evch,dt,mode)** , computes and visualize the correlation matrix between all the channels. mode = 1 is for symmetric operation, mode = 0 is for "time arrow" coincidence (causality). It produces also the map of the matrix.
- **evcho=cl_search(evchi,dt)** , identifies cluster of events and labels the events with the cluster index

Event periodicities

An important point in the event analysis is the study of periodicities. This is performed by the following functions:

- **sp=ev_spec(evch,selev,minfr,maxfr,res)** , that performs the event spectrum; in input we need:

- **evch** event/channel structure
- **selch** channelt selection array (0 excluded channel)
- **minfr** minimum frequency
- **maxfr** maximum frequency
- **res** resolution (minimum 1, typical 6)

pd=ev_period(evch,selch,dt,n,mode,long,narm), event periodicity study (phase diagram); in input we need:

- **evch** event/channel structure
- **selch** channel selection array (0 excluded channel)
- **dt** period
- **n** number of bins of the phase diagram (**pd**)
- **mode** = 0 simple events
  = 1 density normalization; mode(1) = 1, mode(2) = bin width (s)
  = 2 amplitude; mode(1) = 2, mode(2) = 0,1,2 (normal, abs, square)
- **long** longitude (for local periodicities (local solar and sidereal)
- **narm** number of harmonics

SFDB

Theory

The maximum time length of an FFT such that a Doppler shifted sinusoidal signal remains in a single bin is

$$T_{\max} = T_E \cdot \sqrt{\frac{c}{4\pi^2 R_E \nu_G}} \approx \frac{1.1 \cdot 10^5}{\sqrt{\nu_G}}\ s$$

where T_E and R_E are the period and the radius of the "rotation epicycle" and n_G is the maximum frequency of interest of the FFT.

Because we want to explore a large frequency band (from ~10 Hz up to ~2000 Hz), the choice of a single FFT time duration is not good because, as we saw,

$$T_{\max} \propto \nu_G^{-\frac{1}{2}}$$

so we propose to use 4 different SFDB bands:

Short FFT data base

	Band 1	Band 2	Band 3	Band 4
Max frequency per band	**2000.0000**	**500.0000**	**125.0000**	**31.2500**
Observed bands	**1500.0000**	**375.0000**	**93.7500**	**23.4375**
Max duration for an FFT	**2445.6679**	**4891.3359**	**9782.6717**	**19565.3435**
Max len for an FFT (max freq)	**9.7827E+06**			
Length of an FFT (max freq)	**8.3886E+06**			
Length of the FFTs	**8388608**	**4194304**	**2097152**	**1048576**
FFT duration	**2097.15**	**4194.30**	**8388.61**	**16777.22**
Number of FFTs	**9.5367E+03**	**4.7684E+03**	**2.3842E+03**	**1.1921E+03**
SFDB storage (GB)	**160.00**	**40.00**	**10.00**	**2.50**
Storage for sampled data (GB)	**80.00**			
Total disk storage (GB)	**292.50**			

Procedure

- **apply a frequency domain anti-aliasing filter and sub-sample (if 20 kHz data)**

- **high events identification and removal**
  - create a stream with low and high frequency attenuation
  - identify the events on this stream (starting time and length) with the adaptive procedure. After this, this stream is no more used.
  - smooth removal of the events in the original stream (purged stream)
  - estimate the power of the purged stream every minute (or so), creating the **PTS** (power time series)

- **for each of the 4 sub-bands of the SFDB :**
  - (not for the first band) apply anti-aliasing and subsample
  - create the (windowed, interlaced) FFTs, both simple and double resolution: the simple resolution are archived for the following steps, the double is used for the peak map
  - create a low resolution spectrum estimate (**VSPS** - Very Short Power Spectrum, e.g. length 16384)

Software [C environment]

Routines

pss_sfdb

Software [MatLab environment]

There is also a software to create a SFDB using Matlab. This can be used for checking and particular purposes.

- **crea_sfdb(sdsfile,chn,lfft,red)** , can be used also interactively without arguments; **sdsfile** is the first sds file to be processed, **chn** is the channel number, **lfft** is the length of the (non-reduced) ffts, **red** is the reduction factor for the requested band (normally 1, 4, 16, 64). A file sfdb.sbl is created, with the fft collection.

There are also some useful routines:

- **iok=piaspet2sbl(folder,piafilelist,filesbl)** , extracts the "very short" spectra from the Pia SFDB files.

```
folder        folder containing the input pia files
piafilelist   pia file list (obtained with dir /b > list.txt)
filesbl       file sbl to create
```

Time-frequency data quality

[MatLab environment]

The time-frequency data quality analysis is done using

a) the set of power spectra created together with the **SFDB**

b) the set of power spectra created by the function **crea_ps**

c) the high resolution periodograms obtained directly from the **SFDB** FFTs

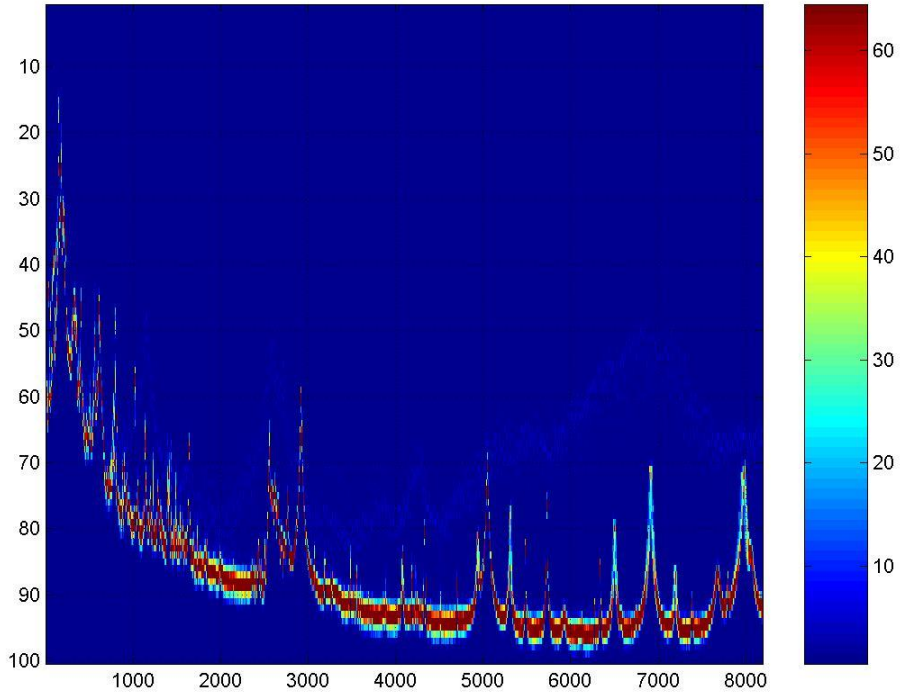
In the cases a) and b), the time-frequency map can be imported in a **gd2** with the function

- **g2=sbl2gd2_sel(file,chn,x,y)** , where file is the **sbl** file containing the power spectra (for example, an **sfdb** file), **chn** the channel number in the **sbl** file, **x** a 2 value array containing the min and the max block, **y** a 2 value array containing the min and the max index of the spectrum frequencies

From this gd2 an array can be extracted and on it the map2hist and imap_hist can be applied:

- **[h,xout]=map2hist(m,n,par,linlog)** , creates a set of histograms, one for each frequency bin, of the various spectral amplitudes of that bin at all the times. **m** is the time-frequency spectral map, **n** is the number of bins for the histograms, **linlog** (= 0,1) determines if the histogram is done on the value spectral values of the spectra or on their logarithms, **par** is the set of parameters to do the histograms:
  - if m is an mx2 array, it contains the min and the max of the histograms
  - if m = 0, the bounds of the histograms are computed automatically by taking the minimum and the maximum of all the data
  - if m = 1, the bounds of the histograms are computed automatically by taking the minimum and the maximum of every bin.

- **imap_hist(h,x,y)** , is used to plot the histogram map; h is the histogram map, x is the frequency value, y the spectral values (if the scale is unique). Here are the two maps for the two cases of par=0 and par=1.


10
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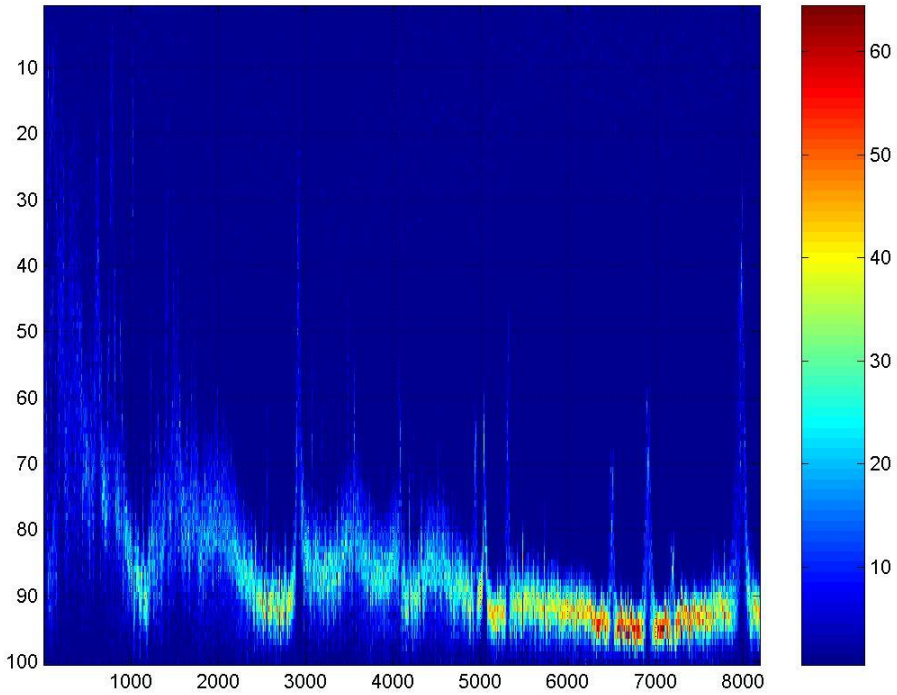
4000
5000
6000
7000
8000
60
50
40
30
20
10


10
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50
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70
80
90
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1000
2000
3000
4000
5000
6000
7000
8000
60
50
40
30
20
10

Peak map

From the SFDB we can obtain the "peak map", i.e. a time-frequency map containing the relative maxima of the periodograms built taking the square modulus of the short FFTs.

To obtain the peak map, the procedure is the following:

- read a short FFT of the data from the database
- using this, construct an enhanced resolution periodogram
- equalize the periodogram, using, for example, the ps_autoequalize procedure
- find the maxima of the equalized spectrum above a given threshold (for example 2)

The stored data can be just 1 and 0 (binary sparse matrix) or also the values of the maxima of the not equalized spectra (this in order to evaluate the "physical" amplitude (instead of the "statistical" amplitude).

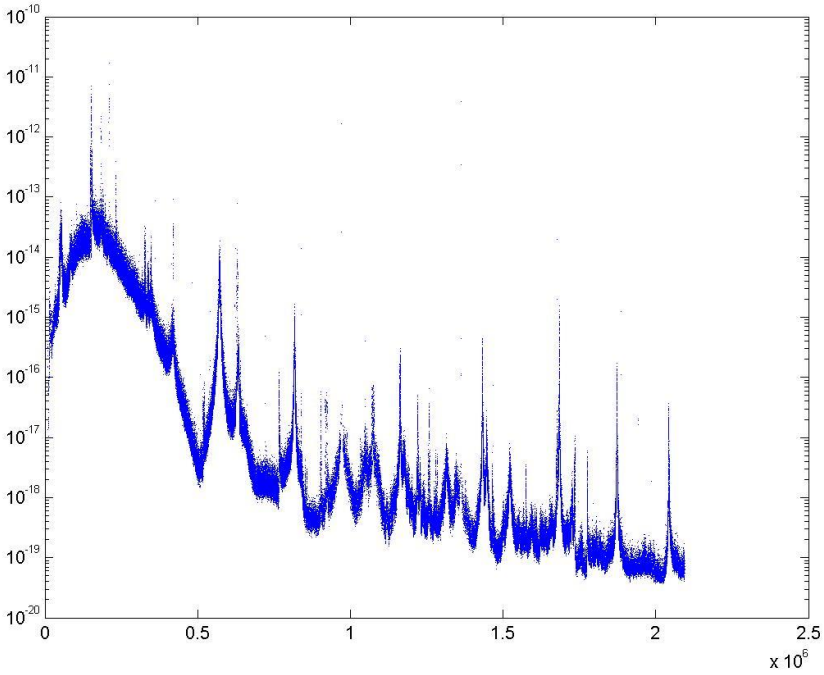
The format of the file can be sbl or vbl, depending if a normal or compressed form is chosen. The peak map file contains all the side information of the SFDB "parent" file.

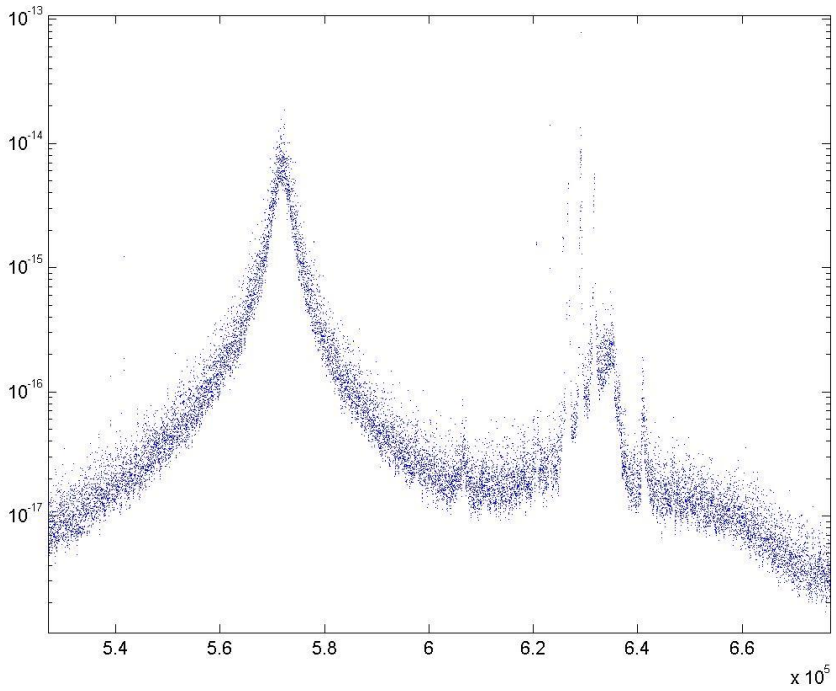
Peak map creation

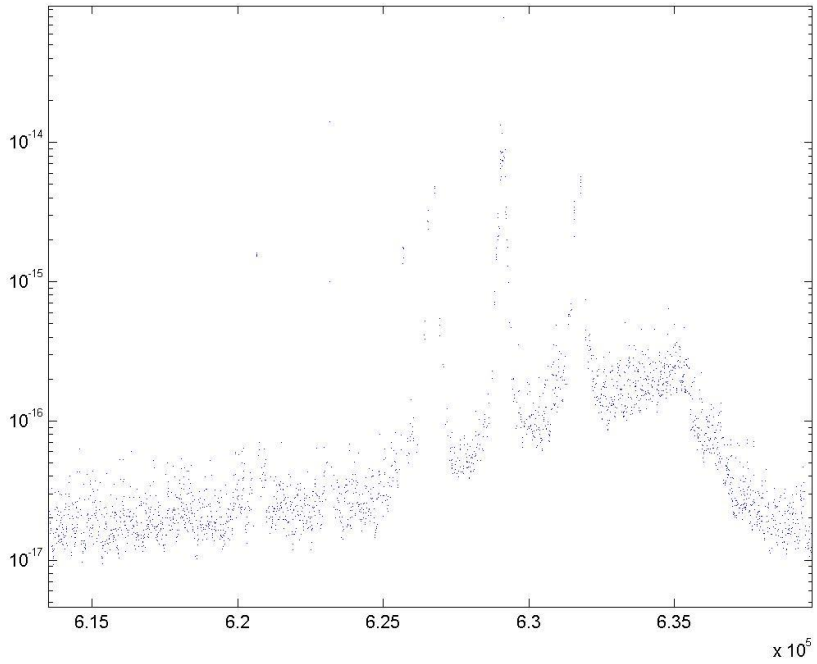
[MatLab environment]

The peak map can be created by

- **crea_peakmap(sblfil,thresh,typ)** , where **sblfil** is the SFDB file, **thresh** is the threshold and **typ** is the type (0 normal with amplitudes, 1 compressed with amplitudes, 2 normal only binary, 3 compressed only binary). Here there is an image of the peak data (with zooms):


10^-10
10^-11
10^-12
10^-13
10^-14
10^-15
10^-16
10^-17
10^-18
10^-19
10^-20
0
0.5
1
1.5
2
2.5
x 10^6


10^-13
10^-14
10^-15
10^-16
10^-17
5.4
5.6
5.8
6
6.2
6.4
6.6
x 10^5



Other peak map creation procedures

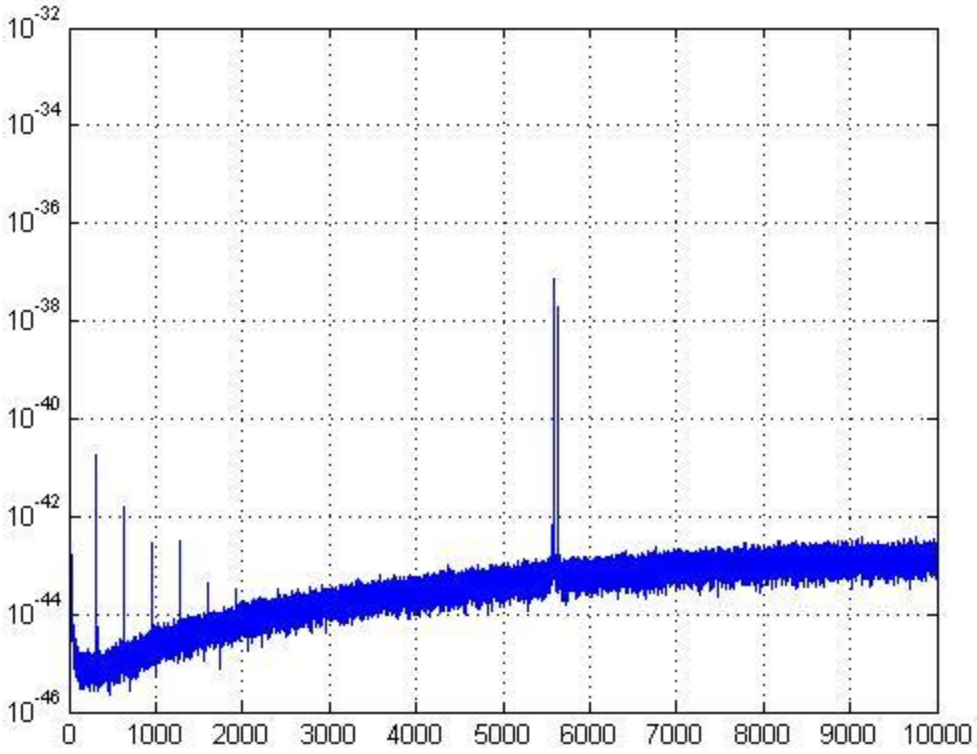
Various techniques have been studied to construct effective peak maps. The main problem is that of the presence of big peaks, that "obscure" the area around.

The basic procedure is the following:

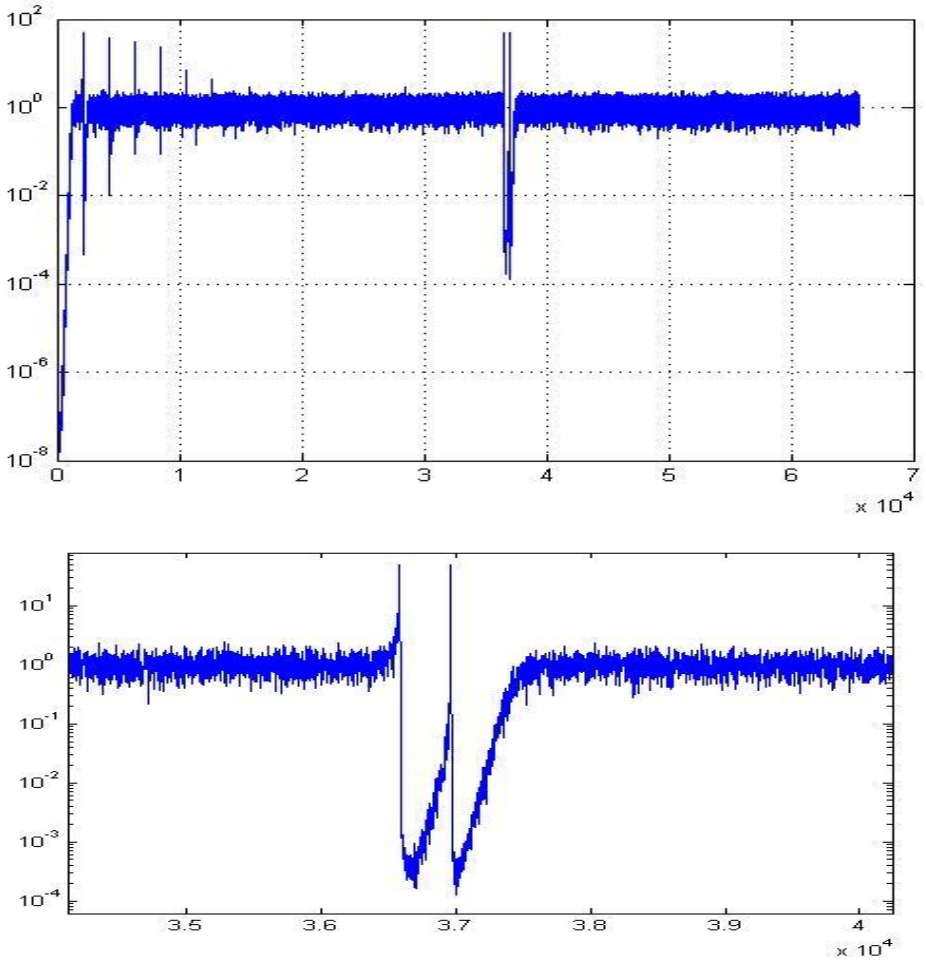
- **[ind,fr,snr1,amp,peaks,snr]=sp_find_fpeaks(in,tau,thr,inv)**, based on the gd_findev function idea, that is adaptive mean computation, with

  - **in** input gd or array
  - **tau** AR(1) tau (in samples)
  - **thr** threshold
  - **inv** 1 -> starting from the end, 2 -> min of both
  -
  - **ind** index of the peak (of the snr array)
  - **fr** peak frequencies
  - **snr1** peak snr
  - **amp** peak amplitudes
  - **peaks** sparse array
  - **snr** the total snr array

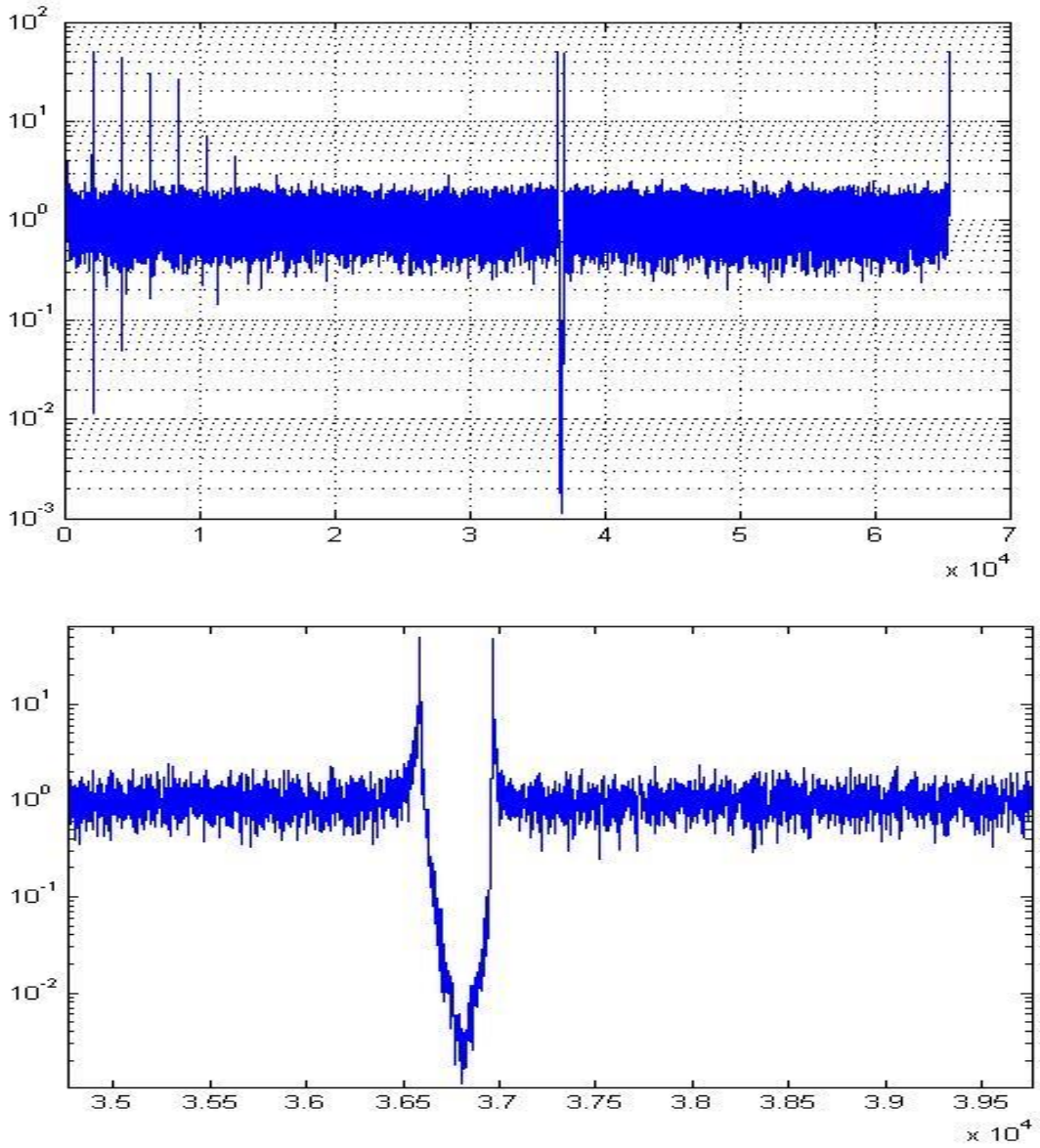
  Applying this procedure to a plot like



We have, with inv=0,



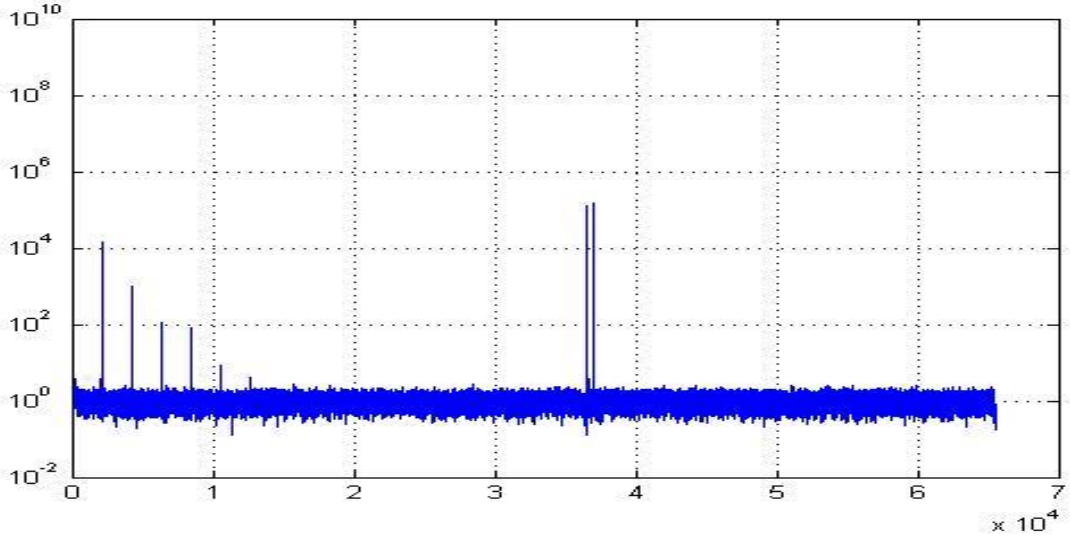
And with inv = 2,

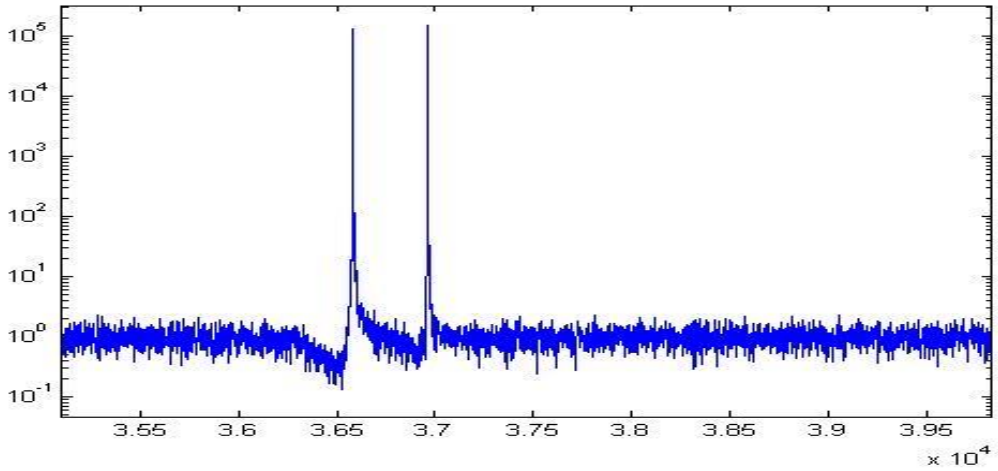


- **[i,fr,s,peaks,snr]=sp_find_fpeaks_nl(in,tau,maxdin,maxage,thr,inv)**, based on the **gd_findev_nl** function idea, that is adaptive mean computation non-linearly corrected, with
  - **in** input gd or array
  - **tau** AR(1) tau (in samples)
  - **maxdin** maximum input variation to evaluate statistics
  - **maxage** max age to not update the statistics (same size of tau)
  - **thr** threshold
  - **inv** 1 -> starting from the end, 2 -> min of both
  -

- **ind** index of the peak (of the snr array)
- **fr** peak frequencies
- **snr1** peak snr
- **amp** peak amplitudes
- **peaks** sparse array
- **snr** the total snr array

Applied to the same spectrum obtains:





Rough cleaning procedure

These procedure is setup to eliminate spurious lines. It is based only on the peak frequency histogram.

```
cd d:\data\pss\virgo\pm\c6

>> [spfr,sptim,peakfr,peaktim,npeak,splr,peaklr,mub,sigb]=…
     ana_peakmap(0,0,0,0,'peakmap-c6_1.vbl');
>> mask=crea_cleaningmask_old(peakfr,5,1.6181);
>> clean_piapeak(mask,'peakmap-c6_1.dat');

>> piapeak2vbl(4000/4194304,4194304,…
     'peakmap-c6_1_clean.dat','peakmap-c6_1_clean.vbl')
```

Frequency domain cleaning procedure

These procedure is based on the frequency histogram of peaks and the a priori knowledge on lines.

The basic function is

- **mask=crea_cleaningmask(peakfr,nofr,nomfr,yesfr,thrblob,thratt)** , with

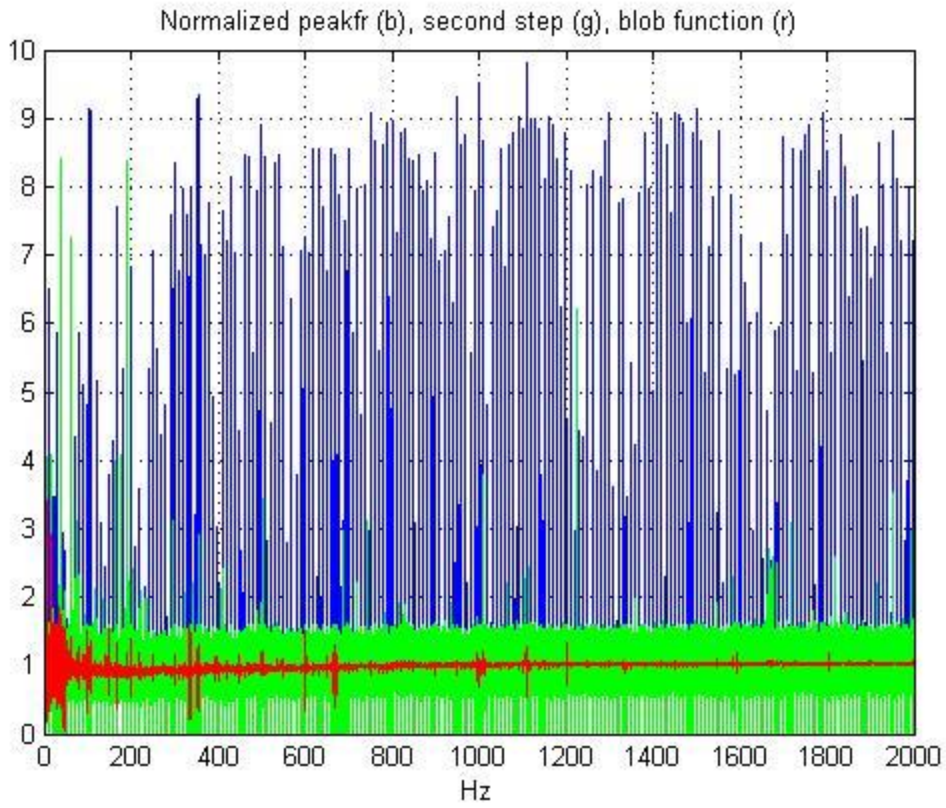
```
peakfr    peakfr (peak frequency histogram) gd
nofr      excluded frequencies; mat[nfr,3] with (centr. freq, band,
              att.band)   0 -> no, <0 -> only attention band
nomfr     excluded frequencies and harmonics; mat[nfr,3] with
             (centr. freq, band, att.band). 0 -> no
yesfr     not excluded frequencies; mat[nfr,2]
              with (centr. freq,band). 0 -> no
thrblob   threshold on unexpected blobs (def = 1.2)
thratt    threshold on attention band (def = 1.6)
```

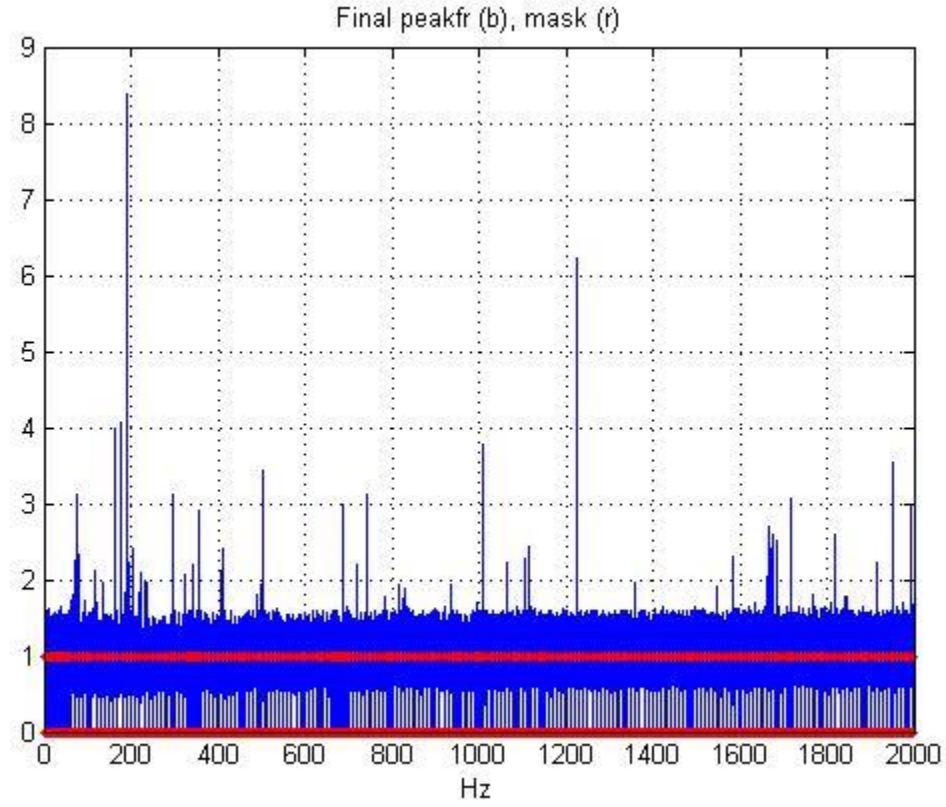
An example of use is by the procedure **crea_mask** :

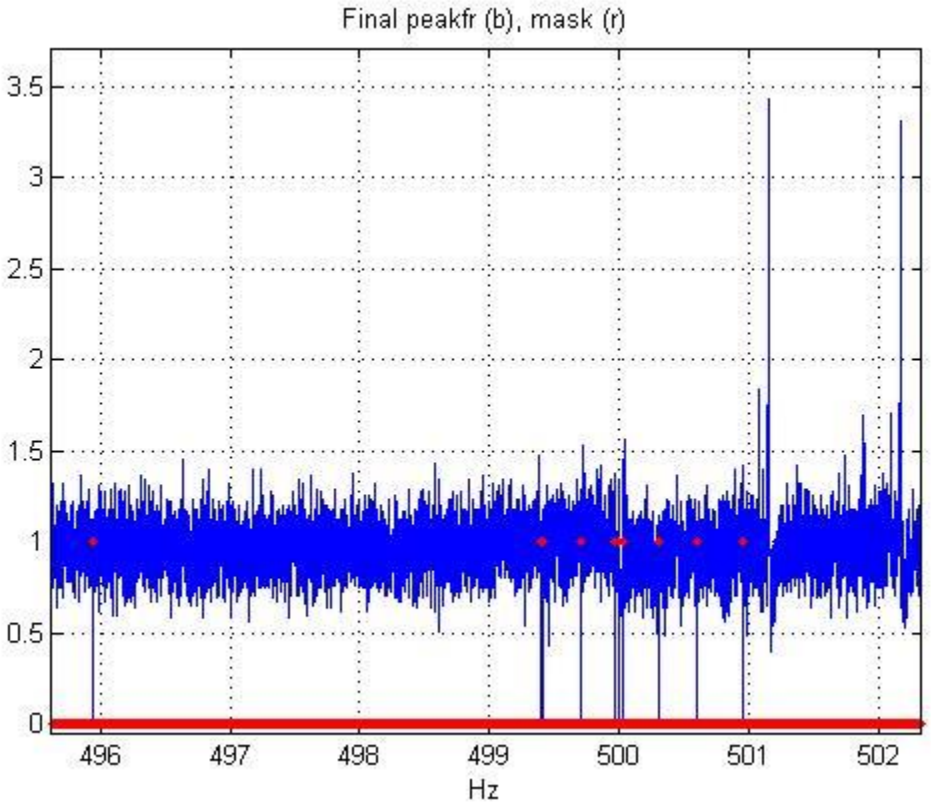
```
% crea_mask

[spfr,sptim,peakfr,peaktim,npeak,splr,peaklr,mub,sigb]=ana_peakmap(0,0,
0,0,'peakmap-C7.vbl');

nofr=read_virgolines(10,2000);

[nl,i2]=size(nofr)

nofr(nl+1,1)=950;
nofr(nl+1,2)=-1;
nofr(nl+1,3)=6;
nofr(nl+2,1)=1002;
nofr(nl+2,2)=-1;
nofr(nl+2,3)=4;
nofr(nl+3,1)=1340;
nofr(nl+3,2)=-1;
nofr(nl+3,3)=10;

mask=crea_cleaningmask(peakfr,nofr,[[10 0 1];[99.1886 0 0.01]],0);
```

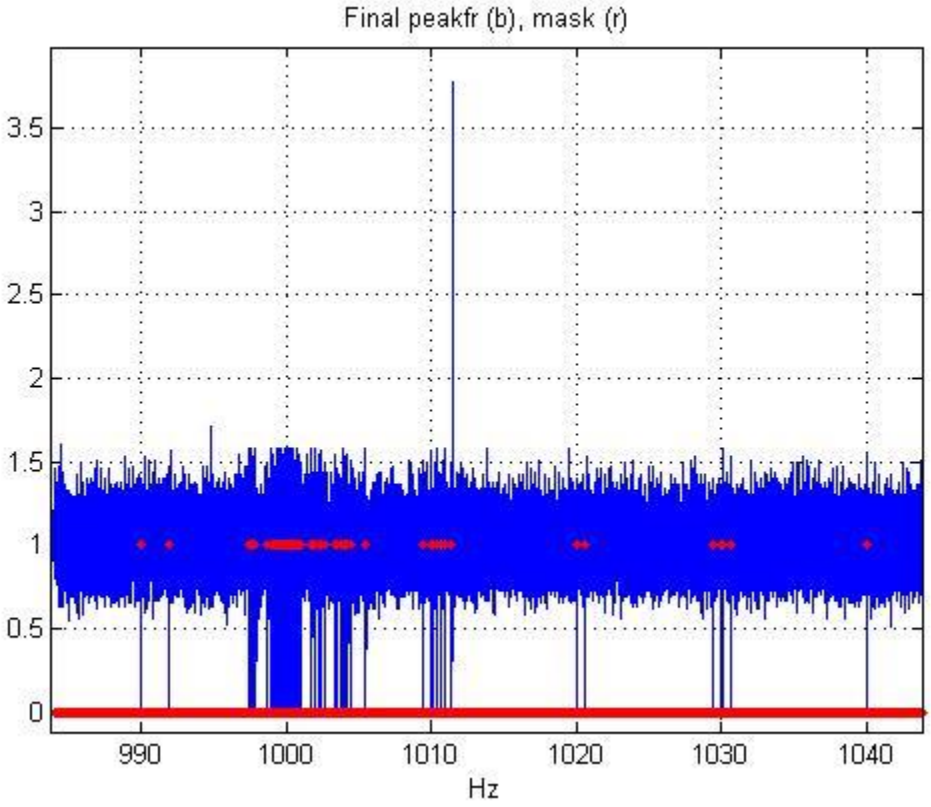
The **read_virgolines** function reads a lines file in Virgo format.

crea_cleaningmask produces also figures to check the mask creation:


Normalized peakfr (b), second step (g), blob function (r)
10
9
8
7
6
5
4
3
2
1
0
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Hz


Final peakfr (b), mask (r)
9
8
7
6
5
4
3
2
1
0
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Hz


Final peakfr (b), mask (r)
3.5
3
2.5
2
1.5
1
0.5
0
496
497
498
499
500
501
502
Hz


Final peakfr (b), mask (r)
3.5
3
2.5
2
1.5
1
0.5
0
990
1000
1010
1020
1030
1040
Hz

Peak map analysis

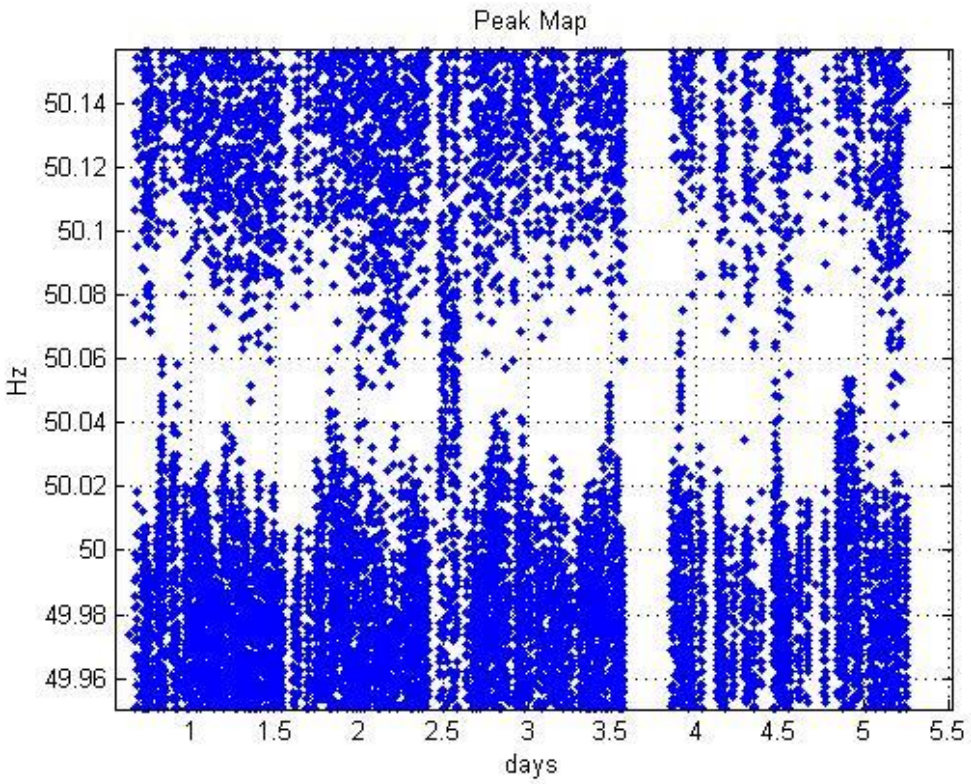
In a "old" vbl-file the first channel is the parameters (as the detector velocity in AU/day), the second the frequency bins number, the third the equalized amplitudes; other channels can contain short spectra and other.
In the "new" vbl-file the first channel is the parameters (as the detector velocity normalized to c), the second the short spectrum, the third the index for the peak vector, the fourth the peak vector, i.e. the frequency bins number, the fifth the equalized amplitudes.

To take the data of the peak map, the following function can be used:

- **[x,y,z,tim1]=show_peaks(frband,thr,time,file)** , where

frband	[min,max] frequency; =0 all
thr	[min,max] threshold (mjd); =0 all
time	[min,max] time (mjd); =0 all
file	input file
x,y,z	peaks data (time,frequency,amplitude)

It shows also the plot of the x,y points.



- **[A tim vel vbl_]=read_peakmap(frband,thr,time,file)** , is similar to show_peaks, but produces a gd2 containing the time-frequency data:

frband	[min,max] frequency; =0 all
thr	[min,max] threshold (mjd); =0 all
time	[min,max] time (mjd); =0 all
file	input file

A	output (a gd2 sparse, with velocities)
tim	times
vel	velocities
vbl_	file header

It can be used for the Hough map snag procedures.

- **[crfr,crtim,peakfr,peaktim,npeak,splr,peaklr,mub,sigb,sphis,spfr,sptim]=ana_peakmap(frband,thr,time,res,file)** , analyzes a vbl-file peakmap.

frband	[min,max] frequency; =0 all
thr	[min,max] threshold; =0 all
time	[min,max] time (mjd); =0 all

res	resolution reduction in frequency in low-res maps; =0 no low-res
file	input file

crfr,crtim	mean cr vs freq and time
spfr,sptim	mean spectrum vs freq and time
peakfr,peaktim	number of peaks vs freq and time
splr,peaklr	t-f peak maxima and number (low-res)
sphis	peak CR histogram
mub,sigm	mean,std of peaks in a spectrum
npeak	total number of peaks

Time-frequency cleaning

The idea is to histogram the peak map in a lower resolution 2D-grid (for example 12 h starting from 6 for time and 0.01 Hz for frequency), then define the maximum allowable value of this histogram for the "normal data" (e.g. 80) and finally cut away the peaks in not-allowable spots. **The cut-away procedure simply change to negative the sign of the frequency of the peaks**.

In practice the procedure, starting from the "dirty" vbl, is the following:

- create the peakmap file list with e.g.: dir *.vbl /s/b > list_VSR2_pm.txt and edit to eliminate blank lines etc.
- edit and execute ana_peakmap_basic.m: this creates the PMC files (peakmap maps).
- This should be done for 5~8 sub-bands each time
- create the PMH files list
- edit and execute ana_PMH, fixing the threshold thresh: this creates the veto array and the vetocell cell array
- apply tfclean_vbl; this creates the new vbls, that have anyway the full information of the cut peaks
- concatenate new vbl files (if needed) with conc_vbl
- check the effect with ana_peakmap_basic_cl.m .

Functions:

- tfclean_vbl
- read_peakmap
- integralF_fromhist
- plot_peaks
- p2rgb
- p2rgb_colormap
- color_points

Script:

- ana_peakmap_basic and ana_peakmap_basic_cl

```
% ana_peakmap_basic

Dfr=5;
VSR='VSR4'; % EDIT

for i = 17:26  % EDIT
    band=[(i-1) i]*Dfr;
    strtit=sprintf(' %s  band %4.1f - %4.1f',VSR,band)
    savestr=sprintf('PMH_%s_%03d_%03d',VSR,band);
```

```
    eval(['[A tim vel vbl_]=read_peakmap(''list_' VSR
'_pm.txt'',band,0,0);'])
    eval(['[x y v ' savestr ']=plot_peaks(A,1,0,1,strtit);'])
    eval(['save(''' savestr ''','''' savestr ''');'])
end
```

- ana_PMH Analyzes PMH and creates time-frequency veto structures
- conc_vbl concatenates vbl files

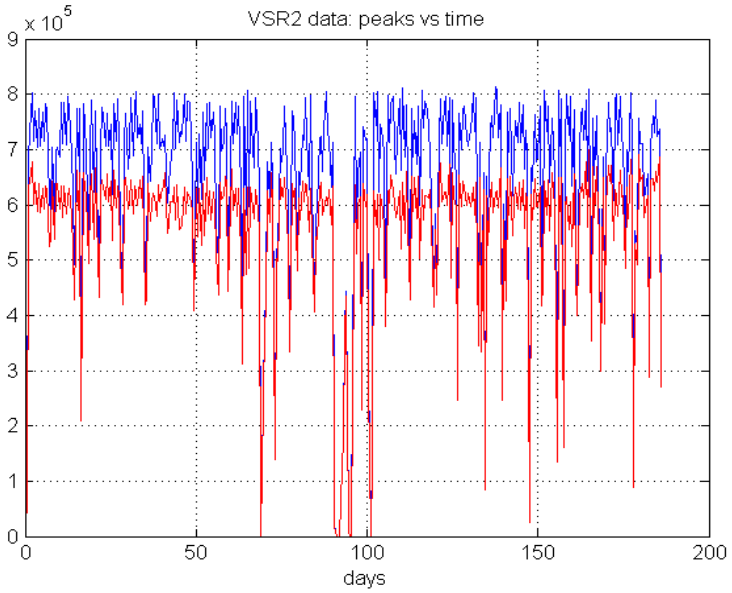
Effectiveness of the procedure on peakmaps

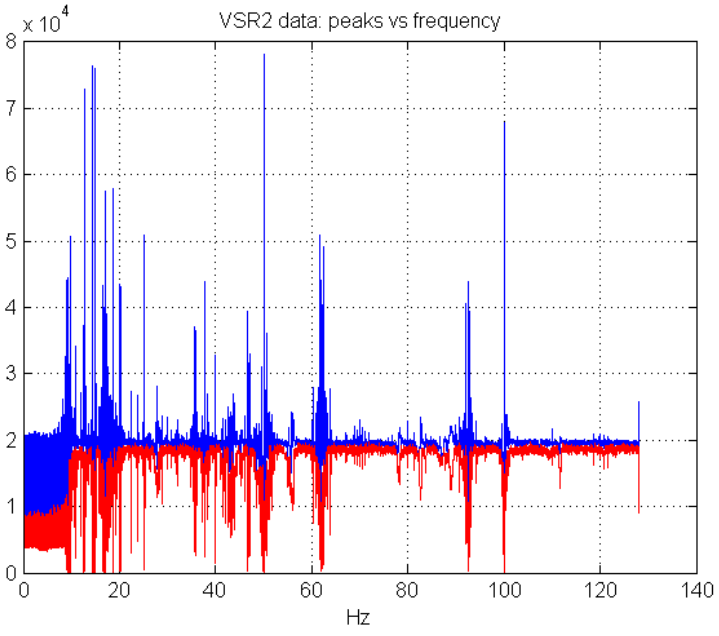
(Using check_PMH)

[Resolution 12 hours/0.01 Hz. Threshold 80]

On VSR2 (blue all, red clean):

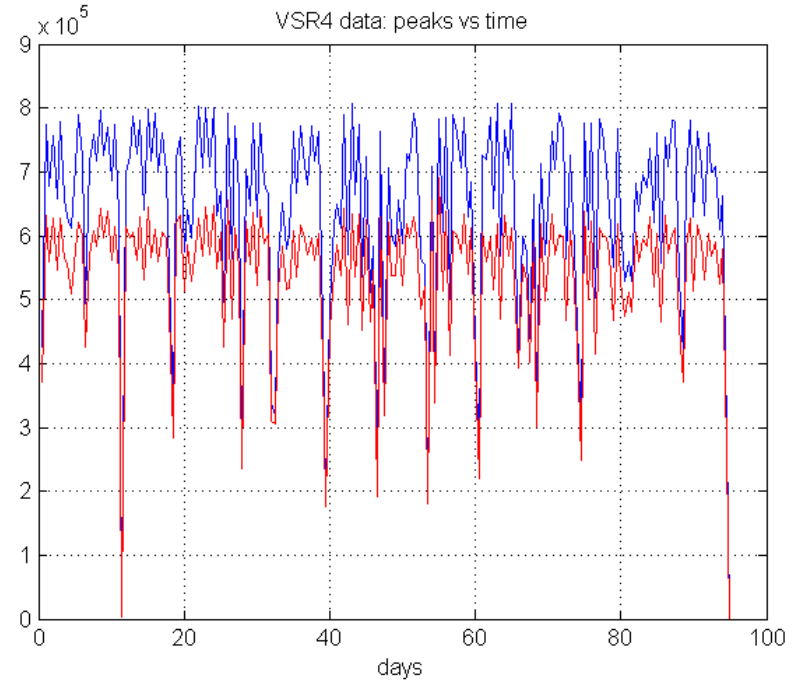
241748723 all peaks, 206402619 cleaned; perc 0.853790

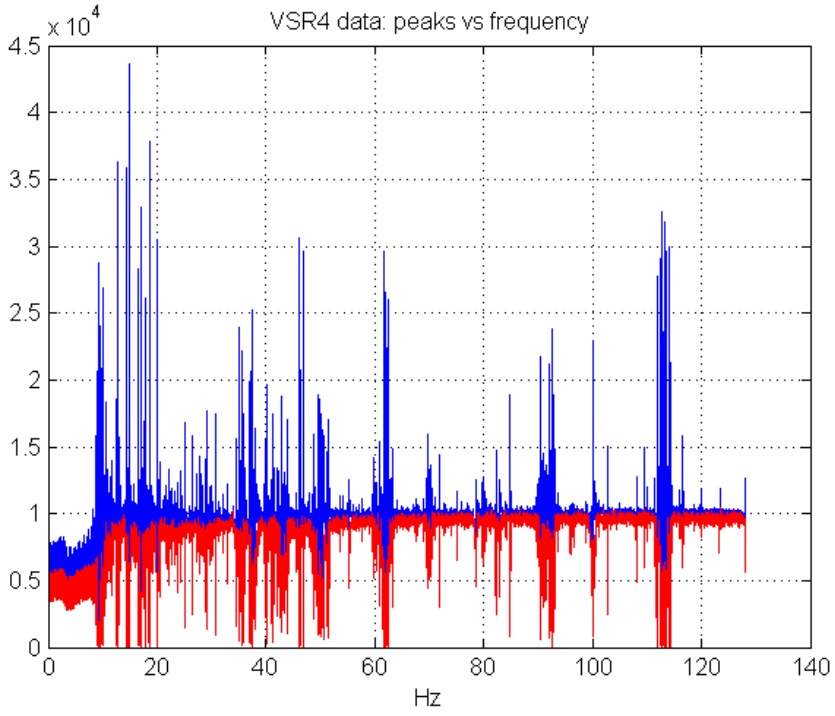




On VSR4 (blue all, red clean):

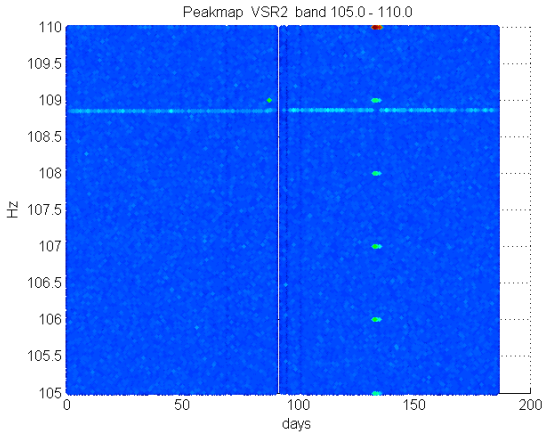
122104240 all peaks, 102300423 cleaned; perc 0.837812

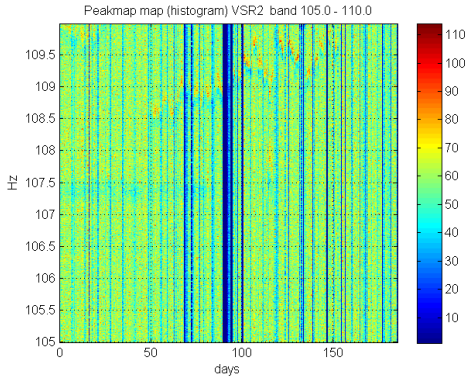




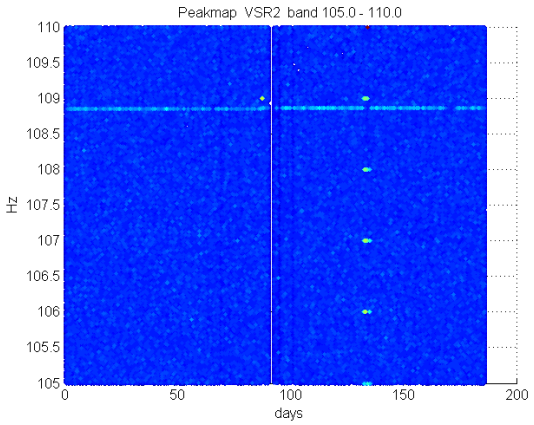
Important: it doesn't cancel gravitational signals. Case of the Pulsar 3:

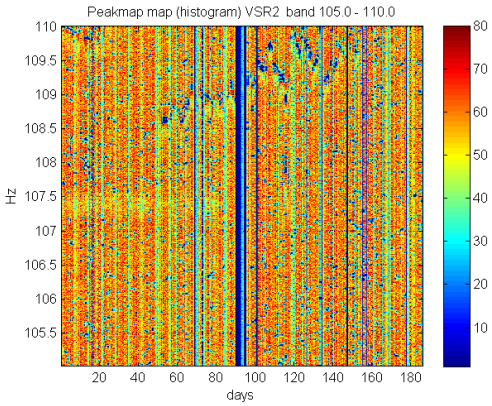
before:





after:





Hough transform ("classical")

[C environment]

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Introduction

This is the User Guide for the PSS_hough library.

PSS_hough is a C library which performs the first (full-sky) incoherent step in the hierarchical procedure developed by the Virgo Rome group for the search of periodic gravitational signals in the data of the Virgo interferometer. The input consists of a peak map file, the output of a candidate file.
For performance reason, the program does not use as input the whole peak map produced in the preceding step of the analysis but small portions of the peak map which are produced at the beginning with the program `crea_input_file` which is described in the Appendix. Once the candidates have been produced they are organized in a candidate database through the program `create_db` which is also described in the Appendix..

Theory

The Hough transform is a robust parameter estimator for patterns in digital images.
It can be used to estimate the parameters of a curve which best fits a given set of points.
The basic idea is that of mapping the data into the parameter space and identifying the
For instance, suppose our data are distributed as a straight line: y=m*x+q. In this case the parameters to be determined are the slope m and the intercepta q. To each point (x,y) a new straight line in the parameter space with equation q=y-m*x corresponds. That is, we can draw a line in the parameter space for each pair (x,y) and all these will intersect in a point (m,q) identifying the parameters of the original line. If noise is present several "clusters" of points will appear in the parameter space.
In our case, the original data are the points in the time-frequency peak map and the

transformed data are points in the source parameter space: $\left(\lambda, \beta, f_0, \dot{f}_0, \ddot{f}_{0,\ldots}\right)$ i.e. source position, frequency and frequency derivatives.
Assuming that there is no spin-down, the relation among each point in the time-frequency plane and the points in the parameter space is given by the Doppler effect equation

$$f_k - f_0 = f_0 \frac{\vec{v} \cdot \hat{n}}{c}$$

where f_k is the frequency of a peak, $\vec{v}$ is the detector velocity vector and $\hat{n}$ is the versor identifying the direction of the source. From this equation we find that the locus of points in the sky to which a source emitting a signal at frequency at f_0 could belong, if a peak at frequency f_k is found, is a circle with radius φ given by

$$\cos\varphi_k = \frac{f_k - f_0}{f_0 \frac{v}{c}}$$

and centered in the direction of the detector velocity vector.
Due to the frequency discretization, in fact we have an "annulus", delimited by two circles Peaks belonging to the same spectrum produce concentric annuli, while moving from one spectrum to the following the center of the annuli moves on the celestial sphere around the ecliptic. Moreover, also the circles radius changes in time, because of the variation of the modulus of the detector velocity vector.
For a given value of the source reference frequency f_0 and spin-down, calculating the annuli corresponding to all the peaks in the time-frequency map and properly summing them, in order to take into account the source spin-down, we compute the Hough map.
For each value of the source reference frequency we have several Hough maps, depending on the number of possible different values of the spin-down parameters.
The number of spin-down parameters that must be taken into account depends on the minimum source decay time, $\tau = \frac{f_0}{\dot{f}_0}$, which we search for. In order to limit the overall needed computing power to a reasonable value, $\tau_{\min} \sim 10^4\, yr$ could be a reasonable choice for the analysis of the whole frequency band over months. This would imply that only the first spin-down parameter should be considered. For shorter observation period, like C6 or C7 Commissioning Runs we can adopt a smaller value for the minimum decay time.
The total number of Hough maps that are built is given by the product of the number of frequencies to be searched for and of the number of values of the first order spin-down parameter. $N_{f_0} \cdot N_{\dot{f}_0}$. On each map a number of candidates is selected putting a suitable threshold.

Implementation

Pss_hough is divided in the following files:

- `pss_hough_drive.c`: module containing the main function and all the functions which are common (at most modulo the data type of the hough map and hough map

derivative) to "standard" and adaptive hough transform: parameters computation, construction of the LUT, reading of the peakmap input file, selection of candidates.

- `pss_hough.h`: header file containing type definitions, global variable declarations, function prototypes, constants, declaration of structures.
- `pss_hough.c`: module containing functions related to the computation of the "standard" Hough transform.
- `pss_hough_adaptive.c`: module containing functions related to the computation of the adaptive Hough transform.
- `Makefile, MakefileAdaptive`: makefiles for compiling and linking the library respectively for the "standard" and adaptive Hough transform.

The library can be divided, from a logical point of view, into four parts.

– Building of the Look Up Table (LUT).
For each search frequency a new LUT is computed (As a matter of fact, the same LUT could be used for more frequencies but for the moment – i.e. as long as observation times are short and then computing times are not too much long - we take a "conservative" approach). Given a search frequency and a spin-down value, we use the same LUT for all the times for which the frequency shift respect to the original one is lower than a given number of frequency bin, 4 in our current default choice. This value is somewhat arbitrary and again conservative: it can be shown that using the LUT for 27 different frequency bins would be enough, and even more at low frequencies.

Given a frequency, the circles corresponding to all the possible peaks in the Doppler band of the chosen frequency are computed. The ecliptic coordinate system is used. As a consequence, the circles have centers in a narrow belt around the ecliptic. This belt is discretized so that ordinates of the circle centers are taken in a discrete set (of 11 different values) while the abscissa is assumed to be zero. Also the sky is discretized in a number of pixels, then two circles with the same center are distinguishable only if their radii differ by at least one pixel.

For each circle center and for each allowed radius, there is a loop on the ordinate values and, correspondingly, the values of the abscissa (as real values) only for the left semi-circle are computed. This is done for performance reasons, since it is then very simple to determine the corresponding right semi-circle using simmetry arguments.

The computed abscissae are stored into an array which is the look-up table. Another array is created, containing the index (along the vertical direction) of the pixels corresponding to the minimum and the maximum ordinate of each circle and cumulative difference between them.

– Reading of the peak map
For each time read the portion of the peak map input file corresponding to the Doppler band around the actual frequency (which takes into account the spin-down). Each read peaks is "translated" into one or more peaks of the LUT: in this way we take into account the fact that the LUT circles are computed for the largest possible velocity and then are

more numerous than the "true" ones (i.e. it may be possible that one peak of the peak map corresponds to two circles of the LUT).

– Calculation of the Hough Map (HM).
The HM is a histogram in the sky coordinates. For each selected peak, two semi-circles are read from the LUT: one corresponding to the current peak and one corresponding to the peak immediately before (in the LUT). This is done because each peak, in a discretized space, produces an annulus of pixels, delimited by a pair of circles. The center of each semicircle is properly shifted, depending on the time index, and the corresponding right half is computed using simmetry; then for each peak we have four semicircles. Semicircles with radius larger than 90 degrees are computed taking the corresponding "opposite" circles with lambda rotated by 180 degrees and beta inversed. To the pixels of the semicircle of each pair (left-right) are assigned values +1 and -1 respectively for the "external" one (and the reverse for the "inner" one), or real values, properly determined, if the adaptive Hough map is computed.

This procedure is applied for each peak of the peak map and for each time the reference frequency is properly shifted in order to take into account the source spin-down.

At the end we have a Hough map derivative (HMD) which is then integrated to produce the final Hough map. For each assumed value of the source spin-down and for each source reference frequency, a HM is obtained. An HM is simply an array of int (or float for the adaptive) containing the number count of each pixel in the sky.

- Selection of candidates
In each HM, pixels where the number count is above a given threshold, are then selected as candidates. Candidate parameters are written in candidate files.

From the user point of view, the library takes at input a binary file containing a portion of the time-frequency peak map and produces a binary file containing selected candidates. The user can choose a number of parameters which will be described in detail in the next section.
Each candidate is described by a set of parameters: frequency, position in the sky (in ecliptical coordinates), first order spin-down value, critical ratio (depending on the number count of its sky cell in the Hough map which it has been selected from, and on the mean and standard deviation of the number count), mean value of the number count of the corresponding Hough map and adimensional amplitude of the corresponding gravitational wave. All these quantities are expressed as integer numbers of "unitary steps" which value is chosen as described in the following table.

Frequency	$10^{-6}\,Hz$	fixed
Position		recomputed every time the search frequency crosses a ten
Spin-down		depends on the assumed spin-down decay time (it is computed once)

Critical ratio	0.001	fixed
Amplitude (adimensional)	10^{-26}	fixed
Mean number count	1	Fixed

The output file can be copied "locally", i.e. on the directory where the executable has been run, or to a remote destination (a Storage Element in the grid terminology) through the grid command lcg-cp. The number of frequencies to be explored is set by the user and cannot overcome the frequency range covered by the input file while the number of first order spin-down values is computed on the basis of the minimum spin-down decay time, which is assigned by the user, according to the relation

$$N_{sd} = \frac{2 f_0^{\max} \cdot N_{FFT}}{2\tau_{\min}\delta f^2}$$

where $f_0^{\max}$ is the maximum searched frequency (default: 2kHz), N_{FFT} is the number of FFT (i.e. total observation time divided by the duration of a single FFT, multiplied by 2 for taking into account the overlapping), $\tau_{\min}$ is the minimum decay time at $f_0^{\max}$ (default: 4000 years), δf is the frequency bin width (inverse of the FFT duration). An over-resolution factor of 2 has been also included. The above equation is obtained starting from the definition we use for the minimum decay time

$$\tau_{\min} = \frac{f_0}{\dot{f}_{\max}}$$

The maximum frequency variation in the observation time is

$$\Delta f_{\max} = \dot{f}_{\max} \cdot T_{obs}$$

Then, the number of spin-down values of the first order is (considering a factor of 2 of over-resolution)

$$N_{sd} = 2\frac{\Delta f_{\max}}{\delta f} = \dot{f}_{\max} \cdot T_{obs} \cdot T_{FFT} = 2\frac{f_0}{\tau_{\min}}\frac{T_{FFT} \cdot N_{FFT}}{2} \cdot T_{FFT} = \frac{2 f_0^{\max} \cdot N_{FFT}}{2\tau_{\min}\delta f^2}$$

The spin-down step is simply

$$\delta\dot{f} = \frac{\dot{f}_{\max}}{N_{sd}}$$

The sky grid is computed starting from the following relation for the mean number of bins in the Doppler band of a given frequency

$$N_{db} = \frac{5}{8}\frac{v}{c}L_{FFT} = \frac{5}{4}\frac{v}{c} f_0 \cdot T_{FFT}$$

where $\frac{v}{c}$ is the ratio of detector to light velocity $\left(\approx 10^{-4}\right)$ and L_{FFT} is the FFT length. The resolution is the inverse of this (the point is that covering the whole Doppler band means covering the whole sky), taking as frequency the upper ten to the current frequency and also a 20% over-resolution factor:

$$\delta \approx \frac{4 \cdot 10^4}{5 \cdot 1.2}\frac{\delta f}{f_0^{\sup}}$$

A log file is produced containing several information on the job and the environment where it has run: parameters used, machine characteristics (OS, cpu type, etc.), timing, etc.

If the adaptive Hough transform must be computed, the user has to specify a detector (default: Virgo); this is needed to calculate the detector response which is a function of the detector geometry and its position and orientation on the Earth. At the moment, only the Virgo and Nautilus detectors are supported.
To switch from the "standard" to the adaptive Hough transform computation some modification to the source code must be done by hand:
- in the header file (`pss_hough.h`) change the data type of `hough_t` and `houghD_t` from `short int` to `float`;
- in the main function (in `pss_hough_drive.c`) comment the call to `houghBuild` and uncomment the call to `houghRad` and `houghBuildAdap`;
- compile the code with `make -f MakefileAdaptive`.
In the future we could decide to use only float type for Hough maps so that no data types difference will exist between "standard" and adaptive computation. However tests have shown that a strong loss of performance happens on machines with a second-level cache (L2) less than 1MB if float data type is used. **This means at least 1MB L2 cache is in any case needed for the adaptive Hough transform to be fast enough**.

The program assumes that the detector velocity vector, read from the input file, is in ecliptical coordinates; however the possibility it is expressed in equatorial coordinates is also foreseen but requires to comment few lines and uncomment few other lines in the function `readPeaks` in `pss_hough_drive.c` (and, obviously, re-compile the program).

The program refers frequencies to the beginning of the observation period. However, it is foreseen the possibility to refer frequencies to an epoch in the past (e.g. to Jan 1, 2000 at 00:00:00): this requires to uncomment a few lines in the function `houghBuild` in `pss_hough.c` (or function `houghBuildAdap` in `pss_hough_adaptive.c`) and re-compiling the program.

In the present implementation, for each search frequency the LUT is re-computed and for each spin-down value a check is done, for every time, if the LUT has to be re-computed. The check consists in measuring the frequency shift at a given time (and a given spin-down value) and comparing it with the maximum allowed shift (as a number of bins). This value can be set by the user. A reasonable value can be obtained in the following way (and probably this computation should be done directly in the code).
The problem is that the LUT is computed initially for a given frequency. When the program analyzes a different frequency, it should refer to a LUT computed for that. However, as we will show, the error done using the "wrong" LUT (i.e computed for a different frequency) is small as long as the difference between the frequencies is small. This means that we can use the same LUT for a small range of different frequencies. To estimate this number, let us compute the variation on the radius of circles as a function of the frequency and at the end let us impose it is less than some reasonable value.
Let us start from the Doppler formula

$$\cos\varphi_k = \frac{f_k - f_0}{f_0}$$

where f_0 is the search frequency and f_k is the frequency of the k-th peak. If we move to the search frequency $f_0 + \Delta f_0$, keeping $f_k - f_0$ fixed, the circle radius will change as

$$\left|\Delta \cos\varphi_k\right| = \sin\varphi_k \Delta\varphi_k = \frac{f_k - f_0}{f_0^2 \frac{v}{c}} \Delta f_0$$

Hence

$$\Delta\varphi_k = \frac{f_k - f_0}{f_0^2 \frac{v}{c} \sin\varphi_k} \Delta f_0$$

The maximum radius variation takes place, for a fixed f_0, when $\sin\varphi_k$ is minimum and $f_k - f_0$ is maximum, i.e. for circle of small radius, that is for thick annuli ("anelli ciotti"). Moreover, the most distant allowed frequency from the search one is given by

$$f_{extreme} = f_0\left(1 \pm \frac{v}{c}\right) \mp \frac{\delta f}{2}$$

because the frequencies refer to the center of the bins (then, moving of half a bin from $f_{extreme}$ we go to the end of the Doppler band).
In this situation we have

$$\left(f_k - f_0\right)_{\max} = f_0 \cdot \frac{v}{c}$$

$$\cos\varphi_{\min} = 1 - \frac{\delta f}{2 f_0 \frac{v}{c}}$$

$$\left(\sin\varphi\right)_{\min} = \sqrt{1 - \cos^2\varphi_{\min}} \approx \sqrt{\frac{\delta f}{f_0 \frac{v}{c}}}$$

where the second order term $\left(\propto (\delta f)^2\right)$ has been neglected.
Then, the maximum variation of circle radius can be written as

$$\left(\Delta\varphi\right)_{\max} \approx \frac{f_0 \frac{v}{c} \Delta f_0}{f_0^2 \frac{v}{c} \sqrt{\frac{\delta f}{f_0 \frac{v}{c}}}} = \frac{\sqrt{\frac{v}{c} \Delta f_0}}{\sqrt{f_0 \delta f}}$$

Now, let us express the change in the search frequency as an integer number of frequency bins

$$\Delta f_0 = l \cdot \delta f$$

and impose that the corresponding maximum variation of the circle radius is less than a fraction of the sky pixel:

$$\left(\Delta\varphi\right)_{\max} = \sqrt{\frac{v}{c} \frac{\delta f}{f_0}} \cdot l \le \varepsilon \cdot \delta\beta$$

with $\varepsilon < 1$. From here we find a condition on the maximum shift on the search frequency in order to have a small variation on the circle radius

$$l \le \frac{\varepsilon \cdot \delta\beta}{\sqrt{\frac{v}{c}\frac{\delta f}{f_0}}}$$

where "how much small" depends on the chosen value of ε.
For a given frequency band the most stringent limit is obtained using the minimum frequency of the band and the maximum value of the v/c ratio which is $\left(\frac{v}{c}\right)_{\max} \approx 1.0222 \cdot 10^{-4}$. A reasonably conservative value for ε could be 0.1. With this choices, and using standard parameters for the frequency and sky resolution we find that $l < 28$ would be enough on the wall frequency band [0,2kHz]. Larger values are allowed at smaller frequencies.

For debugging and test purpose, it also possible (setting the variable WRITE to 1 in `pss_hough.h` and re-compiling the program) to produce some ASCII files containing the last computed Hough map derivative, "extended" Hough map (covering in lambda from –PI to 3PI, i.e. before folding), and Hough map. Also the cumulative Hough map of the whole job can be written (it is meaningful only if the sky grid does not change during the job).

As typical input files cover a small frequency range (a fraction of Hertz), see in Appendix for more details, the analysis of a large frequency band implies the submission of a large number of jobs each analyzing an input file. The management of this (submission, job status checking, retrieval of the output, etc.) is done by the Supervisor program (PSS_SV) which is described in detail in another guide.

Function prototypes

```
long readParameters(int argc, char *argv[], char *, char *, char
*, double *, float *,float *, double *, char *, int *, char *,
char *, char *);
void setParam(char *, double, double, float, double, long long
int *,  double *, double *, int *, long long int *, float *,
double *, int *);
void gridInitialize(double);
void trigInitialize();
void lutBuild(float *,int *);
void DrawLeftCircle(float,float,float,float,int,int,float *);
void houghBuild(FILE *, int, double, double, int, float, float,
char *, double, int);
void houghBuildAdap(FILE *, int, double, double, int, float,
float, char *, double, int, float);
void * readPeaks(double, double, double, char *, double *, int *,
double *, float *, float *, int *, int *, int *, float *);
void DrawCircleNext(float,int,int,int,int,float *,float
*,houghD_t
*);
```

```
void DrawCirclePoles(float,int,int,int,int,float *,float
*,houghD_t *);
void DrawCircleInit(float,int,int,float *,houghD_t *);
void DrawCircleNextAdap(double, float,float,int,int,int,int,float
*,float
*,houghD_t *);
void DrawCircleInitAdap(double,float,float,int,int,float
*,houghD_t *);
void
DrawCircleNextOppAnomalousAdap(double,float,float,int,int,int,int
,float *,float *,float *, houghD_t *);
void hmd2hm(houghD_t *,hough_t *,hough_t *);
void writeMaps(houghD_t *,hough_t *,hough_t *);
int candidates(FILE *,float,double,short int,hough_t *);
void houghRad(char *, float *);
float *radpat_interf();
float *radpat_interf_eclip();
float *radpat_bar();
float *radpat_bar_eclip();
double localSiderealTime(double);
void print_cpu_time();
void get_sys_info();
void get_uname();
void hmcum(hough_t *);
void hmcum2(hough_t *);
void writehmcum();
```

User assigned parameters

These are the parameters that the user can set at command line:

```
tau_f0max=4000.;
thr=3.8;
F0start=49.735069;
format=1;
nfreq=100;
rec_fact=4;
strcpy(caption,”c6”);
strcpy(outdestbase,"gsiftp://virgo-
se.roma1.infn.it/storage/virgo/gwave4t/cristiano/hough_cand/");
strcpy(outdestbase2,"gsiftp://gridse.pi.infn.it/flatfiles/SE00/
virgo/OUTPUT/");
strcpy(outdestbase3,"gsiftp://se01-
lcg.cr.cnaf.infn.it/storage/gpfs_virgo3/scratch/PSS/hough_cand/
virgo/");
strcpy(outdestdir,”local”);
strcpy(detector,”virgo”);
strcpy(fileinput,”/home/Palomba/InputData/”);
strcpy(lfnpath,"local");
```

```
strcpy(db_name,"PSC_DB1");
strcpy(command_file,"nocommandfile");
```

The parameter values are set through the following options:

-d <detector name>
-f <input file>
-x <input file logical file name (with path)>
-e <FFT duration (s)>
-s <spin-down age (yr)>
-t <threshold for candidate selection (units of sigma)>
-p <starting search frequency (Hz)>
-b <name of the candidate database>
-r <maximum allowed frequency shift (n. of bins) for re-computing LUT>
-c <caption>
-o <output destination> (local: retrieve locally)
-W <command file>

Usage example:
./pss_hough -f file_doppler_band_0 –x /grid/virgo/vsr1/file_doppler_band_0 -c vsr1 -o local -e 1048.576 -p 49.735069 -s 4000.000000 -t 3.800000

A command line help is obtained with `./pss_hough --help`

Performance issue

Performance is an important issue for the PSS_hough library. The computation of the Hough transform is the heaviest part of the data analysis procedure and it is then important to have a software as much efficient as possible. The present implementation of the Hough transform computation is the fastest we have developed up to now. Possibly, faster versions will be released in the future.
In the next subsections results of the timing and profiling of the library are given and discussed.

Results of gprof

Machine: grwavcp.roma1.infn.it
Processor: Intel Pentium 4
L2 cache: 1MB
RAM: 1GB

The code has been compiled with options:
`-pg -O3 -ffast-math -funroll-loops -fexpensive-optimizations`

Program parameters:
Search frequency: 330Hz
Number of spectra: 4911 (corresponding to 6 months of data)
RAD=0 (non-adaptive Hough map)

The following profile has been obtained with the unix/linux tool *gprof.*

```
Flat profile:

Each sample counts as 0.01 seconds.
  %   cumulative   self              self     total
 time   seconds   seconds    calls   s/call   s/call  name
 48.02      5.33     5.33   103601     0.00     0.00  DrawCircleNext
 45.95     10.43     5.10   106354     0.00     0.00  DrawCircleNextOpp
  3.42     10.81     0.38     6270     0.00     0.00  DrawLeftCircle
  1.71     11.00     0.19        1     0.19     0.19  writeMaps
  0.36     11.04     0.04        1     0.04    10.53  houghBuild
  0.27     11.07     0.03        1     0.03     0.03  candidates
  0.09     11.08     0.01      799     0.00     0.00  DrawCircleInit
  0.09     11.09     0.01        1     0.01     0.01  hmd2hm
  0.09     11.10     0.01        1     0.01     0.01  readPeaks
  0.00     11.10     0.00      169     0.00     0.00  DrawCircleFin
  0.00     11.10     0.00        1     0.00     0.00  gridInitialize
  0.00     11.10     0.00        1     0.00     0.00  houghInitialize
  0.00     11.10     0.00        1     0.00     0.38  lutBuild
  0.00     11.10     0.00        1     0.00     0.00  readInfoPeakmap
  0.00     11.10     0.00        1     0.00     0.00  readParameters

 %         the percentage of the total running time of the
time       program used by this function.

cumulative a running sum of the number of seconds accounted
 seconds   for by this function and those listed above it.

 self      the number of seconds accounted for by this
seconds    function alone.  This is the major sort for this
           listing.

calls      the number of times this function was invoked, if
           this function is profiled, else blank.

 self      the average number of milliseconds spent in this
ms/call    function per call, if this function is profiled,
         else blank.

 total     the average number of milliseconds spent in this
ms/call    function and its descendents per call, if this
         function is profiled, else blank.

name       the name of the function.  This is the minor sort
           for this listing. The index shows the location of
         the function in the gprof listing. If the index is
         in parenthesis it shows where it would appear in
         the gprof listing if it were to be printed.

                Call graph (explanation follows)
```

```
granularity: each sample hit covers 4 byte(s) for 0.09% of 11.10
seconds

index % time    self  children    called     name
                                                 <spontaneous>
[1]    100.0    0.00   11.10                 main [1]
                0.04   10.49       1/1           houghBuild [2]
                0.00    0.38       1/1           lutBuild [6]
                0.19    0.00       1/1           writeMaps [7]
                0.00    0.00       1/1           readParameters [16]
                0.00    0.00       1/1           readInfoPeakmap [15]
                0.00    0.00       1/1           gridInitialize [13]
-----------------------------------------------
                0.04   10.49       1/1           main [1]
[2]     94.9    0.04   10.49       1         houghBuild [2]
                5.33    0.00  103601/103601      DrawCircleNext [3]
                5.10    0.00  106354/106354      DrawCircleNextOpp [4]
                0.03    0.00       1/1           candidates [8]
                0.01    0.00     799/799         DrawCircleInit [9]
                0.01    0.00       1/1           readPeaks [11]
                0.01    0.00       1/1           hmd2hm [10]
                0.00    0.00     169/169         DrawCircleFin [12]
                0.00    0.00       1/1           houghInitialize [14]
-----------------------------------------------
                5.33    0.00  103601/103601      houghBuild [2]
[3]     48.0    5.33    0.00  103601         DrawCircleNext [3]
-----------------------------------------------
                5.10    0.00  106354/106354      houghBuild [2]
[4]     45.9    5.10    0.00  106354         DrawCircleNextOpp [4]
-----------------------------------------------
                0.38    0.00    6270/6270        lutBuild [6]
[5]      3.4    0.38    0.00    6270         DrawLeftCircle [5]
-----------------------------------------------
                0.00    0.38       1/1           main [1]
[6]      3.4    0.00    0.38       1         lutBuild [6]
                0.38    0.00    6270/6270        DrawLeftCircle [5]
-----------------------------------------------
                0.19    0.00       1/1           main [1]
[7]      1.7    0.19    0.00       1         writeMaps [7]
-----------------------------------------------
                0.03    0.00       1/1           houghBuild [2]
[8]      0.3    0.03    0.00       1         candidates [8]
-----------------------------------------------
                0.01    0.00     799/799         houghBuild [2]
[9]      0.1    0.01    0.00     799         DrawCircleInit [9]
-----------------------------------------------
                0.01    0.00       1/1           houghBuild [2]
[10]     0.1    0.01    0.00       1         hmd2hm [10]
-----------------------------------------------
                0.01    0.00       1/1           houghBuild [2]
[11]     0.1    0.01    0.00       1         readPeaks [11]
-----------------------------------------------
                0.00    0.00     169/169         houghBuild [2]
[12]     0.0    0.00    0.00     169         DrawCircleFin [12]
-----------------------------------------------
```

```
                0.00    0.00       1/1           main [1]
[13]     0.0    0.00    0.00       1         gridInitialize [13]
-----------------------------------------------
                0.00    0.00       1/1           houghBuild [2]
[14]     0.0    0.00    0.00       1         houghInitialize [14]
-----------------------------------------------
                0.00    0.00       1/1           main [1]
[15]     0.0    0.00    0.00       1         readInfoPeakmap [15]
-----------------------------------------------
                0.00    0.00       1/1           main [1]
[16]     0.0    0.00    0.00       1         readParameters [16]
-----------------------------------------------
```

This table describes the call tree of the program, and was sorted by the total amount of time spent in each function and its children.

Each entry in this table consists of several lines. The line with the index number at the left hand margin lists the current function. The lines above it list the functions that called this function, and the lines below it list the functions this one called. This line lists:

index A unique number given to each element of the table. Index numbers are sorted numerically. The index number is printed next to every function name so it is easier to look up where the function in the table.

% time This is the percentage of the `total' time that was spent in this function and its children. Note that due to different viewpoints, functions excluded by options, etc, these numbers will NOT add up to 100%.

self This is the total amount of time spent in this function.

children This is the total amount of time propagated into this function by its children.

called This is the number of times the function was called. If the function called itself recursively, the number only includes non-recursive calls, and is followed by a `+' and the number of recursive calls.

name The name of the current function. The index number is printed after it. If the function is a member of a cycle, the cycle number is printed between the function's name and the index number.

For the function's parents, the fields have the following meanings:

self This is the amount of time that was propagated directly from the function into this parent.

children This is the amount of time that was propagated from the function's children into this parent.

called This is the number of times this parent called the function `/' the total number of times the function

was called. Recursive calls to the function are not included in the number after the `/'.

name This is the name of the parent. The parent's index number is printed after it. If the parent is a member of a cycle, the cycle number is printed between the name and the index number.

If the parents of the function cannot be determined, the word `<spontaneous>' is printed in the `name' field, and all the other fields are blank.

For the function's children, the fields have the following meanings:

self This is the amount of time that was propagated directly from the child into the function.

children This is the amount of time that was propagated from the child's children to the function.

called This is the number of times the function called this child `/' the total number of times the child was called. Recursive calls by the child are not listed in the number after the `/'.

name This is the name of the child. The child's index number is printed after it. If the child is a member of a cycle, the cycle number is printed between the name and the index number.

If there are any cycles (circles) in the call graph, there is an entry for the cycle-as-a-whole. This entry shows who called the cycle (as parents) and the members of the cycle (as children.) The `+' recursive calls entry shows the number of function calls that were internal to the cycle, and the calls entry for each member shows, for that member, how many times it was called from other members of the cycle.

```
Index by function name

  [12] DrawCircleFin           [8] candidates              [6] lutBuild
   [9] DrawCircleInit         [13] gridInitialize         [15]
readInfoPeakmap
   [3] DrawCircleNext         [10] hmd2hm                 [16]
readParameters
   [4] DrawCircleNextOpp       [2] houghBuild             [11]
readPeaks
   [5] DrawLeftCircle         [14] houghInitialize         [7]
writeMaps
```

Comments

It is clear from the profiling that most of the time is spent in the functions DrawCircleNext and DrawCircleNextOpp. This is due to two facts:

1. these functions are called a number of times equal to the number of circles which must be 'drawn'. The time spent in each call is about 50 microseconds.
2. In these functions a large array, the Hough map derivative, is accessed in a random way and this results in a large number of cache misses. If we could access it in a more regular way, a gain in performances of at least a factor of 2 could be obtained. We will try to reduce this bottleneck in the next releases of the library.

Compiling the library with the *pgcc* compiler, performances improve by about 20%.
Similar results are obtained taking a search frequency in the highest frequency band (500Hz-2kHz).
For lower bands (<31.25Hz; 31.25Hz-125Hz), the weight of the functions DrawCircleNext and DrawCircleNextOpp gradually decreases because the dimension of the Hough map derivatives becomes smaller and, consequently, decreases the number of cache misses.

A useful way to compare the code performances on different platforms is to compute the "equivalent number of clock cycles" needed to increase by 1 the number count in a given pixel of a Hough map.
In the following table some results are reported for different values of the search frequency f. The other parameters are the same as those given at the beginning of the previous section.

	Pentium 4	Pentium 4	Xeon	Opteron 64 bit
CPU (GHz)	2.8	2.8	2.4	2.2
L2 cache (MB)	1	1	.512	1
compiler	gcc 3.2	pgcc 6.1	gcc 3.2	gcc 3.2
f=20Hz	40	34	41	29
f=80Hz	43	34	64	32
f=320Hz	69	57	79	70

Appendix

In this Appendix we describe two programs that are to be meant as part of the PSS_hough library: one, `crea_input_file`, produces the input files used by the Hough program starting from the full peak map file; the other, `create_db`, collect candidates produced by the Hough jobs in a database that is used in the next steps of the analysis.

crea_input_file

This is a program developed to produce input files for the Hough program. It starts from the time-frequency peak map and produces a set of files each being a portion of the original peak map covering a small frequency range. This is needed for two reasons:

1. if input file for the hough program is put in the grid sandbox, and then is copied to the working node at submission, it cannot be larger than a few MB at most, to avoid network problems;
2. even if input to the Hough program is already at the site where the job will run, it proves not efficient to open several times the full big peak map and read the small portion that a single job will analyze.

The frequency range covered by each input file is chosen on the basis of a compromise between the need to not have too many files to be processed and to not have jobs lasting too much. The choice adopted in the analysis of C6 and C7 during 2006 has been 0.1Hz for C6 and 0.5Hz for C7. For C6 this means more than 10000 jobs to cover the frequency range 50-1050Hz and for C7 2100 jobs over the same frequency range.

Input parameters

-l <file with the list of peak map files>
-f <overall start search frequency>
-g <start search frequency for the current job>
-u <number of files to be produced>
-q <number of frequencies covered by each file>
-o <location of output files>
-s <type>
`normal`: use input peak map (default)
`flat`: all peaks
`random`: uniform peak distribution

Usage example:

```
./crea_input_file -l lista_c7_clean.txt  -f 49.735069 -g
48.609733 -u 2100 -q 500 -o
/home/palomba/InputData/c7_clean/prova/
```

create_db

This is a program developed to perform 2 operations using the candidate files produced by the Hough jobs:

1. creation of the candidates database structure;
2. fill the database with candidates files.

The candidate database structure is described in the PSS_UG to which the reader can refer to for more details. Here we simply give the basic information needed to understand how the program works. More details can be found in the programming guide `create_db_PG.doc`.

The candidate database consists of a hierarchy of directories covering the frequency range from 0 to 2kHz.
The 'standard' configuration consists of 20 directories each covering 100 Hz, each containing 10 directories each covering 10Hz.
Each '10Hz' directory contains one (standard) or more files containing candidates for that frequency range.

Program schematic description

The program gives two possibilities:

1. create a new database and fill it with candidate files;
2. fill an existing database.

For each candidate, it checks, on the basis of its frequency, if it goes into the currently open candidate file, or in a (currently close) already existing file or in a new file to be created. The new candidate file is created if needed and some parameters are computed (and written in the candidate file): frequency index respect to 0Hz (in units of `freq_step`), steps in lambda, beta, and spin-down. Other parameters are read from the first file produced by the Hough code.
The number of candidate files written and the total number of candidates are shown at the output.

Input parameters

Options (`./create_db -help`):

-f <starting frequency (Hz)>
-g <FFT duration (s)>
-d <frequency band (Hz)>
-l <list of files to concatenate>
-q <number of files to concatenate>
-i <input files path>
-c <file caption>
-b <DB base name> (with /)
-e <file frequency width> (default: 10Hz)
-w <DB name caption> (e.g.: PSC-DB_c7-clean_<caption>)
-t <Maximum spin-down age (at 2kHz, yr)> (default: 4000)
-p <Number of spectra> (default: 556)

Usage example:

```
./create_db -f 49.735069 -g 1048.576 -d 1100. -l
list_cand_c7_sim_clean.txt -q 2100 -i ./PSC_DB-c7_sim_clean/ -c
c7_sim_clean -b ./PSC_DB-c7/ -e 10 -w new -t 4000 -p 556
```

The program is compiled with: `cc create_db.c –o create_db –lm`

Function prototypes

```
void readParameters(int, char *[], float *, float *, char *, int
*, char *, char *, char *);
void createDBStructure(float,float, char *);
void populateDB(char *, int, char *, char *, char *);
void extractDir(int, char *, char *);
int computeDecina(int);
int computeStep(int, long long int *, float *, float *, float *,
int *);
```

[MatLab environment]

pss_explorer

pss_hough

Hough transform ("f/f_dot")

Theory

The Hough transform...

Implementation

As said in the previous section, …

Peak-map cleaning

The first step of the f/f_dot Hough transform is the analysis without Doppler shift, that identifies the disturbance lines. This is done "once" for short runs and "per decades" in case of long runs.

The found h-peaks are archived in ASCII files (one for each analysis: e.g. one per decade in case of long runs) with the following format (described per lines):

- the decade or run
- the original sampling time
- the length of the original FFT
- the frequency step
- the spin-down epoch
- the spin down min, max and step
- the number of FFTs

Then, for each frequency decade:

- the frequency band with a ">Fr.Band:" at beginning
- the number of original peaks of the peak-map
- the mean value of the Hough map
- the total number of found h-peaks
- one line for each h-peak with: frequency, spin-down, Hough map peak amplitude

---

On the basis of this file we can modify the vbl peakmap files, in order to "flag" the disturbance peaks. This is achieved changing the "INDEX" vector (that gives the frequency) to its negative values at the flagged peaks.

Supervisor

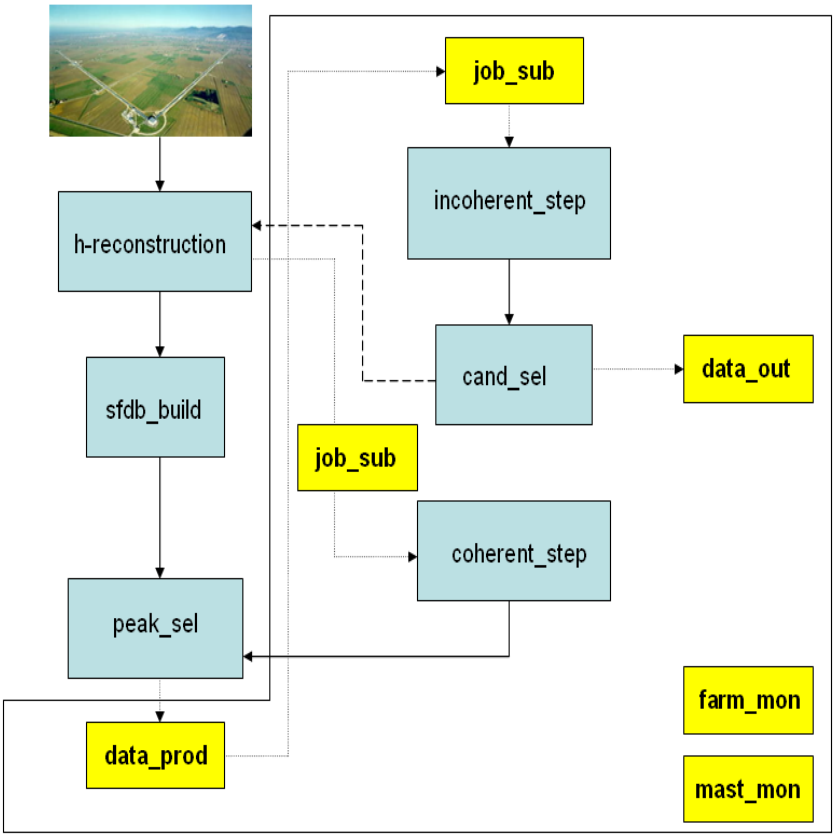
Basics

We call **Supervisor** (SV) the ensemble of services and programs we are developing for farm/job management. It is built on top of a batch system which controls job scheduling and load balancing (PBS, see later for a more detailed description). The batch system can be customized according to the user's needs; the SV in some cases uses the PBS API functions. Let us see how the SV enters in the general scheme for the hierarchical procedure developed for the periodic sources search.
Schematically, these are the main steps in the data analysis procedure:

1. **build SFDB**: construction of the SFDB from the h-reconstructed data;
2. **peak selection**: selection of peaks in the periodograms obtained from the SFDB;
3. **incoherent step**: the peaks are the input of the HT;
4. **candidate selection**: candidates in the output of the HT are selected;
5. **coherent step**: initial data are corrected, longer FFTs are calculated and a new peak-map is produced.

Steps 2-5 are repeated until the length of FFTs is equal to the total observation time.
The SV enters in:
peak selection: after peak selection, a service running on the master node, **data_prod,** will produce input files for the HT; each input file will consist of lists of peaks corresponding to a given frequency band (plus the components of the detector velocity vector).
incoherent step, coherent step: in these phases a service, **job_sub**, is dedicated to job submission and workload management on the farm nodes. Note, concerning the coherent part of the analysis, that at least the first coherent step will be performed on several processors because the computing power needed, though small with respect to what we need for the first incoherent step, is not negligible.
candidate selection: after candidate selection, a service running on the master node, **data_out**, copies output files (two kinds of files, one containing candidates and the other containing information on the jobs) on the storage.
steps (2,5]: a service, running on the master is dedicated to the monitoring of farm nodes and of PSS-jobs; a service, running on "secondary masters", is dedicated to the monitoring of the master node.

In the following picture the relation between the main steps in the data analysis procedure and the Supervisor services is outlined. In particular, monitoring services, i.e. farm_mon and mast_mon, are not tied to a specific point of the analysis chain but act on the whole 'space' delimited by the 'box'.


job_sub
incoherent_step
h-reconstruction
cand_sel
data_out
sfdb_build
job_sub
coherent_step
peak_sel
farm_mon
data_prod
mast_mon

Outline of the supervisor

We call **master** the node where the active SV is running: it is the machine from where most of the management is done; we call **slave**, or **Computing Node** (CN), a machine where calculations are done; the master will be also a CN. We call **Storage Element** (SE) the machine where data (both input and output) are stored.
We assume the cluster is on a private network, with the masters (both "primary" and "secondary") as the only interface to the LAN. Secondary masters are CN which can replace the master if this fails. Moreover, some of the CN can be also part of a grid farm.
We distinguish two types of jobs: *PSS_jobs* , which are directly managed by the SV, and *N-jobs* which run on the CN. In general, we can think a PSS-job as made of several N-job, plus some information.
Now, we list the main steps in the SV activity:

1. **supervisor start**: SV starts on the master;
2. **master monitoring start**: SV starts the master monitoring service on "secondary" masters; "secondary" masters are ordered according to the rank (active master has rank 0, the second one has rank 1 and so on)
3. **node status monitoring**: SV periodically checks the status of all CN and produce a report;
4. **master status monitoring**: on each "secondary" master a service periodically checks the status of all the masters of greater rank and, if no active master exists, the node where it is running becomes the new primary master and start farm management;
5. **input data production**: The active SV produces input data on the master;
6. **job submission**: The active SV starts the *PSS-job:* creates a PSS-job folder on the SE and manages the workload of the CNs;
7. **job status monitoring**: The status of a *PSS-job* is periodically monitored (querying the node(s) where it is running), saved on a file and distributed among all the secondary masters. This is needed if the active master crushes and must be replaced by another one. The status of a *PSS-job* contains the information listed in **ref A**.
8. **output file copy**: The final results of each *N-job* are stored in the PSS-job folder on the SE; a copy is kept also on the node where the job run.

ref A: the status of a PSS-job contain the following information:

- the name of the submitting machine (the master);
- the submission time;
- on which CNs (one or more) and which of these, if any, have the (sleeping) SV;
- the workload distribution (i.e. the *N-jobs*: name, submission time, input data,….);
- all the important events (end time of a *N-job*, and the exit status, crashes, problems,….).

All these information are collected in a file and also in a C structure.

Implementation of the Supervisor

The steps outlined in the last paragraph can be translated in a number of services which "form" the SV program and which we have already introduced in the previous section:

a. data_prod: Production of input data files starting from the SFDB;

b. job_sub: Job submission, workload management and retrieval of output files;

c. data_out: Management of output files;

d. farm_mon: Monitoring of PSS-jobs and slave nodes;

e. mast_mon: Monitoring of master node.

The mapping between the SV steps and services is the following:

SV activity	Service
node status monitoring	farm_mon
master status monitoring	mast_mon
input data production	data_prod
job submission	job_sub
job status monitoring	farm_mon
output file copy	data_out

In the following figure a schematic view of the SV services and their relation with the cluster environment is given.
In the implementation of the services we sometimes rely on the PBS batch system. This has been conceived for job distribution and workload management and gives to the user a set of commands also for job/node/queues monitoring. In particular, we use the *Batch Interface Library* (IFL) which provides a set of user callable functions with, approximately, a one to one correlation with client commands.

Candidate database and coincidences

The database (FDF)

The candidates are stored in text files, with many check informations.
The relevant information contain:

- ecl. long. λ
- ecl. lat. β
- frequency ν
- spin down d
- amplitude A
- CR (global)
- Uncertainty on λ
- Uncertainty on β

Starting from these files a practical database is created.

The parameters archived in the files are, for example:

```
% FrBand  [Hz] 19.800000 23.800000
% VETO Average, Median and std of the hough map;  187.752249   197.579648
46.121870
% VETO Threshold thresC (n*sigma)    372.239727
% VETO Sel. of peaks to be vetoed with 0 s.d. CR Average, CR std 16.897884
10.074178
 % % VETO frequency,  spin down,  Candidate Amplitude, CR
% %  19.999951   7.626998e-12   2175.503186   43.097796
% %  20.556470   7.626998e-12   1822.882285   35.452380
% %  20.999951   7.626998e-12   874.638571   14.892855
% %  21.337476   7.626998e-12   421.780901   5.074136
% %  21.999951   7.626998e-12   834.369456   14.019753
% %  22.999951   7.626998e-12   1104.227264   19.870726
% first file of the decade
/storage/gpfs_virgo4/virgo4/RomePSS/virgo/pm/VSR2/v3/256Hz-
hp20/CLEAN/peak_20090707-256Hz-1_cl.vbl
% original sampling time [s] 3.906250e-03
% lenght of the FFTs  2097152
% Peakmaps frequency step [Hz] 1.220703e-04
% Beginning mjd time of the analysis 55019.680150
% Used mjd epoch  55111.702702
% ====New Subband analyzed. Candidate Amplitude 1  7807138
 % Coarse spin down min,max,step  [Hz/s] -6.864298e-11 7.626998e-12 7.626998e-12
 % Frequency over resolution factor 10
```

```
 % Total FFTs number 3616
% FrBand  [Hz] 19.799390 23.800610
% Fraction done; Sky grid position done (n) lambda beta [deg]; 0.001418 1
0.000000   28.428098
% Average, Median and std of the hough map;  187.358149   197.528903   43.597255
% Number of candidates per Sky patch 49.000000
 % FIRST STEP candidates:  frequency [Hz] lambda [deg]  beta [deg]  spin down
[Hz/s]  Candidate Amplitude, CR
%   20.49836424     0.0000    28.4281     7.62699775e-12       395.162       4.766
%   21.80302732     0.0000    28.4281    -6.10159820e-11       384.591       4.524
%   22.73776853     0.0000    28.4281     0.00000000e+00       377.203       4.355
%   22.10618894     0.0000    28.4281    -3.81349887e-11       375.209       4.309
…….
% RESULTS around the found candidates for one Sky patch
% Refinement factor in Spin down; In the Sky Grid 5 2
% around the original position: lambda and beta [deg] = 0.000000 28.428098
% Average, Median and std of the hough map;  187.358149   197.528903   43.597255
% Spin down step [Hz/s] ; Ncandidates per patch 1.525400e-12 49.000000
% frequency [Hz] lambda [deg]  beta [deg]  frequency [Hz]   spin down [Hz/s] Cand
Amplitude  CR DDl DDb
 20.49844969   0.0000   29.5139    1.22031964e-11      447.301       5.962  0.786  1.388
 21.80296629   0.0000   29.5139   -5.33889842e-11      205.011       0.405  0.786  1.388
 22.73778074 359.6078   28.1208   -6.10159820e-12      381.483       4.453  0.786  1.388
 22.10605467   0.3922   28.1208   -3.05079910e-11      302.401       2.639  0.786  1.388
 20.49771726 359.6078   28.1208   -3.96603883e-11      208.130       0.476  0.786  1.388
 21.68985594 359.6078   28.1208   -5.03381851e-11      230.063       0.980  0.786  1.388
 22.73787840   0.0000   29.5139   -5.33889842e-11      239.638       1.199  0.786  1.388
 22.77130125   0.3922   28.1208   -1.83047946e-11      360.222       3.965  0.786  1.388
….
```

The old database (Old Hough)

Periodic Source Candidates are stored in particular huge data bases, named **PSC_DB**. In this case only one spin-down parameter is considered.

A PSC_DB is a collection of files and folders, contained in a folder with name PSC_DBxxxxxx .

This folder contains

- a **readme.txt** file,
- a data-base creation log file **psc.log**,
- a doc file **psc.doc** with the documentation,
- a **psc.dat** file that is a script with peculiarities of that DB, like the starting time, the sampling time, the length of the ffts, the number of spin-down parameters, the antenna coordinates,…
- 20 folders named **0000**, **0100**, **0200**,…., **1900**

each of these folders contain 10 folders named **00**, **10**, **20**,…., **90** and each of these last contain 10 files, one for each hertz of starting frequency. The name of the files refer to the name of the PSC_DB and to the covered frequency range, for example, **pss_cand_1394.cand** or **pss_cand_0101.cand** .

This type of database is called "**type 1**" (**db1**)

Each file has the following structure:

Header			
protocol (old: 1 normal, 2 coin 2nd group new: 3 normal, 4 coin 2nd group)	**.prot**	**int4**	**1-4**
caption	**.capt**	**char128**	**5-132**
initial time (mjd)	**.initim**	**double**	**133-140**
sampling time	**.st**	**double**	**141-148**
FFT length	**.fftlen**	**int8**	**149-156**
initial frequency bin of the file	**.inifr**	**int8**	**157-164**
delta lambda	**.dlam**	**float**	**165-168**
delta beta	**.dbet**	**float**	**169-172**
delta sd (Hz/day)	**.dsd1**	**float**	**173-176**
delta CR	**.dcr**	**float**	**177-180**
delta mean Hough map (mh)	**.dmh**	**float**	**181-184**
delta h	**.dh**	**float**	**185-188**
number of spin-down	**.nsd1**	**int4**	**189-192**

epoch (1 = epoch 2000, 0 = epoch .initim)	**.epoch**	**int4**	**193-196**
free (now 15 int4)			**197-256**
Any candidate			
frequency (at epoch of initial time or epoch 2000, depending on .epoch) (in units of microHz)		**uint4**	**1-4**
lambda index		**uint2**	**5-6**
beta index (from -90)		**uint2**	**7-8**
sd1 index		**int2**	**9-10**
CR index		**uint2**	**11-12**
mh index		**uint2**	**13-14**
h index		**uint2**	**15-16**

Note that the single candidate have 7 parameters and 8 16-bit words: this is the why that we use, in Snag, "raw" candidate 8*N uint2 vectors, used only for rapid disc access, and "fine" candidate (7,N) double matrices, with the seven parameters for each candidate.

The lambda and beta index start from 0 value.

If the data-base contain 10^9 candidates, each file should contain about 500,000 candidates. So the mean value for the dimension of the file is

500000*16+256 ~ **8 MB**

and the total dimension of the data base should be about **16 GB**.

To perform the coincidence analysis, the files are supposed to be sorted. This can be accomplished by the function **psc_reshape_1**.

The problem of the "type 1" database, in case of big databases, is the long coincidence time (performed by the **psc_coin_ 1** function) .

Type 2 database

Better results can be achieved with the "**type 2**" database.
In this case, a single sorted file is created for each 10 Hz group (named e.g. **pss_cand_1390.cand** or **pss_cand_0100.cand**). Then, from each of these, (24*10+2)=242 files. The number 1-240 are 15*15 degrees patches in the sky, the 241 is the 15 degrees radius south pole zone and the last the 15 degrees radius north pole. These new files are created by **psc_reshape_db2**. So the data for each 10 Hz band are both in a single file (possibly, but not necessarily frequency sorted) and in the 242 sky patch files, allowing best results for each type of search.

Regarding the sky patch files, note that now there is an asymmetry between the two coincidence groups, and the second coincidence group should be a little larger (in area), in order to perform coincidence with neighbors also at the edge of the patches.

Type 3 database

Another database structure is the "**type 3**". Also in this case, a single sorted file is created for each 10 Hz group (named e.g. **pss_cand_1390.cand** or **pss_cand_0100.cand**). Then from this a file for each spin-down value is created., e.g. **pss_cand_0230_sd0002.cand** or **pss_cand_0240_sd-022.cand** (for negative spin-down). These new files are created by **psc_reshape_db3**. So the data for each 10 Hz band are both in a single file (possibly, but not necessarily frequency sorted) and in the n different spin-down files, allowing best results for each type of search.

For coincidence purpose, all the database files are supposed to be sorted in frequency.

Basic functions

The candidates are stored in vectors (of dimension 8*N), as they are read from files, or matrices (of dimensions [7,N]), in physical units (remember that the frequency uses 2 variables). Normally the matrix is "wrapped" in a structure with other information, like the epoch.

Operating on files

- **psc_wheader(fid,pss_cand_head)** writes a psc file header

- **candstr=psc_rheader(fid)** reads the header of candidate file, producing a structure.

- **[A,nread,eofstat]=psc_readcand(fid,N)** reads the candidates of candidate file

fid	file identifier
N	desired number of candidates
A	candidate vector
nread	number of obtained candidates
eofstat	= 1 end of file

- **cand=psc_type(n1,n2,notype,file)** produce a candidate matrix and types candidates from file

n1,n2	min,max sequence number
notype	>0 no type
file	candidate file

- **head=check_psc_file** checks the consistency of a pss candidate file

- **psc_reshape_1(dirin)** pss candidate files post-processing, type 1 **(obsolete)**

- **psc_reshape_db2(op,dirin,dirout,infr1,infr2)** type 2 pss candidate files post-processing

  op operation:
  0 -> sort input files

1 -> to 242 files (first coincidence group) (contains sort)
2 -> to 242 files (second coincidence group) (contains sort)

dirin input directory (root)
dirout output directory (root)
infr1,infr2 min,max value of frequency groups (def 1 - 200)

- **psc_reshape_single(op,prefilout,filin,dirout)** pss candidate files post-processing (type 2) - single input file

op operation:
0 -> sort input files
1 -> to 242 files (first coincidence group) (contains sort)
2 -> to 242 files (second coincidence group) (contains sort)

prefilout first piece of output file names
filin input file)
dirout output directory (root

Operating on candidate vector

- **fr=psc_readfr(candvect)** reads frequencies from vector candidate; in the files the data are read as UInt16

candvect contains single candidates information as groups of 8 uint16
the first 2 uint contain the frequency information

- **mcand=psc_vec2mat(vcand,head,nn)** converts a candidate vector 8*n to a candidate matrix (7,n)

vcand candidate vector
head candidate header structure
nn how many candidates (at most)

Operating on candidate matrix

- **candout=psc_sel(candin,fr,lam,bet,sd,cr)** candidate selection

candin input candidate matrix (7,n)
fr [frmin,frmax]; = 0 no selection
lam [lammin,lammax]; = 0 no selection
bet [betmin,betmax]; = 0 no selection
sd [sdmin,sdmax]; = 0 no selection
cr [crmin,crmax]; = 0 no selection

- **out=psc_show(cand,typ,pars)** shows PSS candidates; the data can be previously selected with psc_sel

cand candidate (7,n) matrix
typ type of show: 'freq','freq0','sky','sd','cr','mh'
pars parameter structure, depending on type
out output result, depending on type

Other functions

- **k=psc_kfiles(lam,bet)** which of the 242 files to take (vector version)

lam,bet ecliptic coordinates (degrees)

- **cand1=psc_sortcand(cand)** sorts candidate arrays of different types

Analyzing the PSC database

Searching for coincidences in the PSC database

There are some Matlab procedures to search for coincidences between two candidate sets:

- **[c_cand1,c_cand2]=psc_coin(dircand1,dircand2,freq,searstr,resfile)** search for candidates in a complete type 2 data base, producing 2 candidate matrices

```
dircand1    candidate first directory (with last \)
dircand2    candidate second directory (with last \)
freq        [min max] frequencies; 0 all;
            [fr1, fr2, .., frn] if n > 2 frx multiple of 10 Hz (start)
searstr     search structure
resfile     result file
```

```
type-2 psc-db is in files of 10 Hz, each group in 242 sky patches
```

- **[c_cand1,c_cand2]=psc_coin_single(dircand1,dircand2,searstr,resfile)** analogous to the preceding one, but operating on a single file type 2 db

- **psc_coin_2fil(file1,file2,searstr,resdir)** similar to the preceding ones, but operating on two single files.

- **[c_cand1,c_cand2]=psc_coin_list(dircand,listcand,searstr,resfile)** search coincidences between a list of candidates (for example a list of known or fake sources) and a type 2 candidate db.

Coincidence analysis

A coincidence file can be analyzed by the program **psc_anacoin**.

It produces a psc structure, whose elements are the following:

```
psc          psc structure
 .level      level (1 candidate, 2 coincidence
             candidate, n n-groups coincidence
             candidates)
 .width      normalized coincidence width

 .sear       search structure
   .diffr    frequency difference
   .diflam   lambda difference
   .difbet   beta difference
   .sd1      sd1 difference

 .N(n)       number of candidates
 .initim(n)  initial time
 .fftlen(n)  fft length

 .dfr(n)     frequency quanta
 .dlam(n)    lambda quanta
 .dbet(n)    beta quanta
 .dsd1(n)    sd1 quanta
 .dcr(n)     cr quanta
 .dmh(n)     mh quanta
 .dh(n)      h quanta

 .nfr(n)     frequencies numbers
 .nlam(n)    lambdas numbers
 .nbet(n)    betas numbers
 .nsd1(n)    sd1s numbers

 .fr(:,n)    frequencies
 .lam(:,n)   lambdas
 .bet(:,n)   betas
 .sd1(:,n)   sd1s
 .cr(:,n)    crs (critical ratios)
 .mh(:,n)    mhs (mean Hough)
 .h(:,n)     hs (h amplitudes)
```

Coherent follow-up

Known source

The basic pipeline for known source, starting from the decade SFDBs, is the following:

- Extract the band in an sbl file
- From this, create a uniformly sampled gd, corrected for the source Doppler and spin-down
- Eliminate bad periods
- Eliminate big events
- Create the "Wiener" filtered data
- Do the maximum length power spectrum
- Apply the matched filter and the coherence
- Check the value at the expected frequency vs the distribution of the filtered spectrum

The details are in the following sub-sections.

Extract the band in an sbl file

This step is done by

[iok sbl_]=sfdb09_band2sbl(freq,cont,folder,pialist,filesbl,simpar)

where

- **freq** frequency band [min max] (rough); n -> whole band, n is the number of
- blocks per file
- **cont** output file content: 1 -> only data
- 2 -> data and velocity/position (double)
- 3 -> data, velocity/position (double) and short spectrum band
- **folder** folder containing the input pia files
- **pialist** pia file list (obtained with dir /b/s > list.txt)
- **filesbl** file sbl to create; if simX.sbl -> simulation :
- sim0.sbl only sinusoid, classical
- sim1.sbl only sinusoid, frequency domain
- sim2.sbl data plus sinusoid
- sim3.sbl white noise

- sim4.sbl only source, naive
- sim5.sbl only source, fine
- **simpar** simulation parameters (e.g.: [frequency amplitude])
-
- iok = 0 -> error
- **head** header of the output file

An example is the following:

[iok sbl_]=sfdb09_band2sbl([22.25 22.5],2,'','O:\pss\virgo\sfdb\VSR1-v2\list2.txt','v_B.sbl');

In list2.txt there is the list of the sfdb09 files to work on. E.g., (the list is created by **dir /S/B/O > list2.txt** then edit and check)

O:\pss\virgo\sfdb\VSR1-v2\deca_20070727\VIR_hrec_20070727_025306_1.SFDB09
O:\pss\virgo\sfdb\VSR1-v2\deca_20070727\VIR_hrec_20070727_171336_100.SFDB09
O:\pss\virgo\sfdb\VSR1-v2\deca_20070727\VIR_hrec_20070728_051336_200.SFDB09
O:\pss\virgo\sfdb\VSR1-v2\deca_20070727\VIR_hrec_20070728_175136_300.SFDB09
O:\pss\virgo\sfdb\VSR1-v2\deca_20070727\VIR_hrec_20070729_105745_400.SFDB09
O:\pss\virgo\sfdb\VSR1-v2\deca_20070727\VIR_hrec_20070730_045326_500.SFDB09
O:\pss\virgo\sfdb\VSR1-v2\deca_20070727\VIR_hrec_20070730_193526_600.SFDB09
O:\pss\virgo\sfdb\VSR1-v2\deca_20070727\VIR_hrec_20070731_085006_700.SFDB09
O:\pss\virgo\sfdb\VSR1-v2\deca_20070727\VIR_hrec_20070801_042216_800.SFDB09
O:\pss\virgo\sfdb\VSR1-v2\deca_20070727\VIR_hrec_20070803_133416_900.SFDB09
O:\pss\virgo\sfdb\VSR1-v2\deca_20070727\VIR_hrec_20070804_125026_1000.SFDB09
O:\pss\virgo\sfdb\VSR1-v2\deca_20070727\VIR_hrec_20070805_005026_1100.SFDB09
O:\pss\virgo\sfdb\VSR1-v2\deca_20070727\VIR_hrec_20070805_163616_1200.SFDB09
O:\pss\virgo\sfdb\VSR1-v2\deca_20070806\VIR_hrec_20070806_013606_1.SFDB09
O:\pss\virgo\sfdb\VSR1-v2\deca_20070806\VIR_hrec_20070806_133606_100.SFDB09
O:\pss\virgo\sfdb\VSR1-v2\deca_20070806\VIR_hrec_20070807_014426_200.SFDB09
O:\pss\virgo\sfdb\VSR1-v2\deca_20070806\VIR_hrec_20070807_194426_300.SFDB09
O:\pss\virgo\sfdb\VSR1-v2\deca_20070806\VIR_hrec_20070808_130726_400.SFDB09
……..

It creates an sbl file with an user header, read by **sfdb09_us=read_sfdb_userheader(sbl_)**, containing the information of the sfdb09 header.
Note: in sbl_.dt there is the normal time between 2 ffts.
The program is rapid: 2 months of data are processed in about a quarter of an hour.

There is also the possibility to do different simulations (in some cases, much slower).

For sfdb09 files created before 15 Apr 2010, use sfdb09_band2sbl_rad2.

Create a uniformly sampled gd, corrected for the source Doppler and spin-down

This step is done by

[g vv pp]=pss_band_recos(source,filein,nn0,gdname)

where

- source [frequency,alpha,delta] source (Hz,deg) easy source; 0 -> no correction
- source structure: fine source
- filein input file (sbl file created at the preceding step)
- nn0 imposed reduced fft length (a sub-multiple of original fft length)
- gdname name of the saved gd (or nothing or 0)
-
- g output gd
- vv detector velocity (in the SSB, in c units)
- pp detector position (in the SSB, in light s)

The data produced are complex.

In the case of "fine source" (well known source), it uses the parameters of the source Snag structure (Vela case):

```
          a: 1.288358812083750e+002
          d: -44.823645805527782
        v_a: -49.680000000000000
        v_d: 29.899999999999999
     pepoch: 54157
         f0: 22.382394913120621
        df0: -3.125054539948422e-011
       ddf0: 2.524864601014520e-021
     fepoch: 54157
        t00: 51544
        eps: 1
        psi: 0
          h: 1.000000000000000e-023
        snr: 1
         fi: 0
      coord: 0
   chphase: 0
```

and for every SFT the structure (in practice frequency, position and epochs) is updated by the function **sourupd=new_posfr(sour,t).**

The position of the Detector in the SSB is computed at each time sample, by the values of the position and velocity at the central point of the data chunk that produced the SFT (this information is inside the SFDB09 and in the sbl files).
If the nn0 is not provided, the programs computes the shortest possible value.

Eliminate bad periods

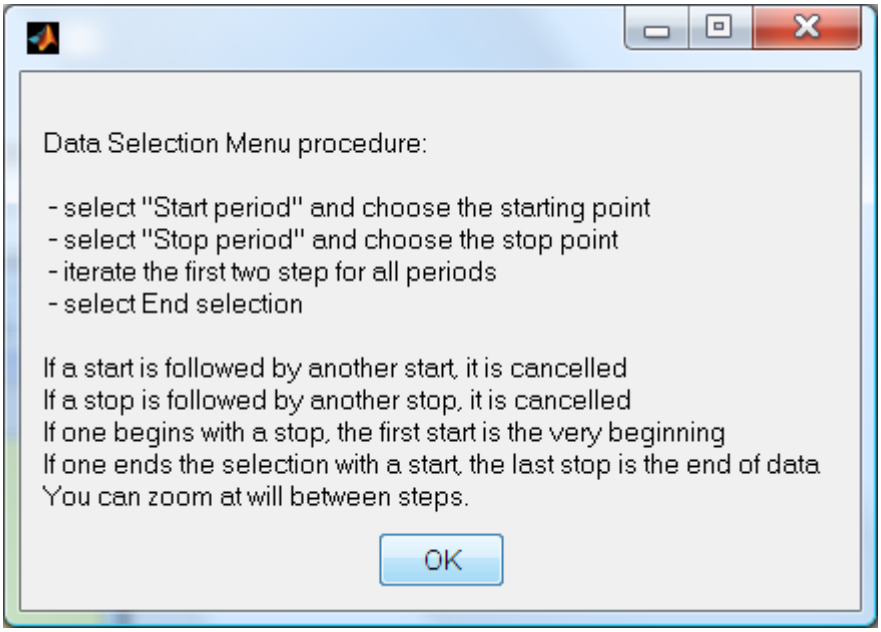
This step is accomplished interactively, by the help of the function

gd_null_absc(typ,g,gdoutname)

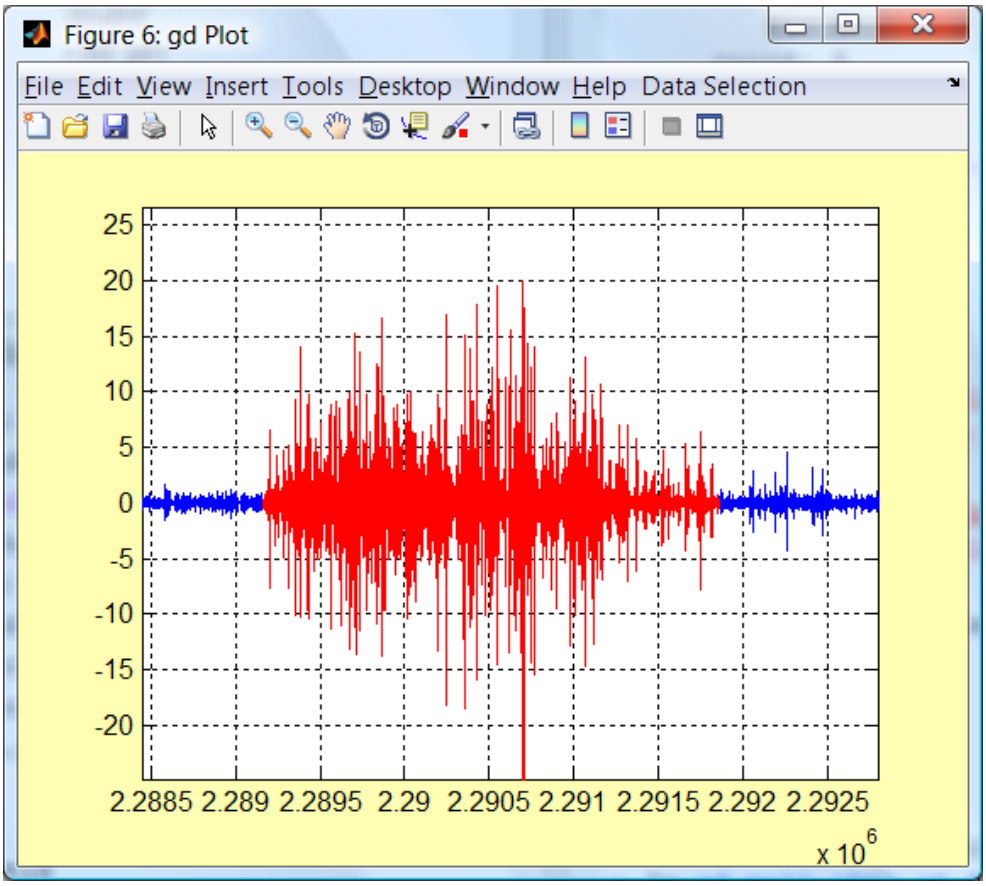
- The input data can be a gd or array
- The output is a gd or array
-
- typ 0 linear, 1 logx, 2 logy, 3 logx,y
- g ordinate or gd or array
- gdoutname name of the output gd

The program is not standard: the out is not produced directly by it, but by a set of three other programs that communicate with it by global variables (start_sel_9399.m, stop_sel_9399.m and end_null_9399.m).

The help appears at start, as:


Data Selection Menu procedure:
- select "Start period" and choose the starting point
- select "Stop period" and choose the stop point
- iterate the first two step for all periods
- select End selection
If a start is followed by another start, it is cancelled
If a stop is followed by another stop, it is cancelled
If one begins with a stop, the first start is the very beginning
If one ends the selection with a start, the last stop is the end of data
You can zoom at will between steps.
OK

When a period is selected (to be nullified), it appears in red:



Only when all the periods have been selected, we should press the "End selection" menu option and the new gd is created, together with a file with the selected periods, e.g.:

Operating on gb gd or array
Producing gou gd or array

tini tfin - iini ifin:

1748462.882278 1749764.369128 1738078 1739379
2270617.689045 2292445.264693 2260233 2282060
1060921.112908 1062486.537651 1050536 1052102
2448896.803872 2451522.136453 2438512 2441137
3653292.076651 3656007.448343 3642907 3645622
3667115.787082 3671312.270605 3656731 3660927
3721670.072888 3748823.789805 3711285 3738439
4080296.473596 4082828.398386 4069911 4072443

The file can be edited to cancel or add periods.

The new gd is "cleaned"and we should operate on it for the following step.

There are two utilities that operate on the generated file:

- `gout=re_apply_null(gin,file)` where gin is the original gd and file is the null period file produced by the preceding program; gout is the "nullified" file.

- `gdcell=extract_null(gin,file)` where gin is the original gd and file is the null period file produced by the preceding program; gdcell is a cell array containing the gds with the nullified periods. A plot with the original data and the nullyfied data in read is produced.

Eliminate big events

This is accomplished by the program

[gout gsigmf]=ada_clip_c(gin,den,lenstat,cr,typ)

where:

- gin input gd or array
- den density of log bins (bins per unit interval, typically 10)
- lenstat length of stationarity (number of samples)
- cr critical ratio for clipping
- typ type of clipping:
- 0 -> clipped value (default)

- 1 -> zero
- 2 -> interpolate ! NOT YET IMPLEMENTED
- 3 -> eliminate data ! NOT YET IMPLEMENTED

The output is the clipped gd and the estimated varying-time standard deviation. This functions operates on complex gds.

Create the "Wiener" filtered data

The data produced are now cleaned, but their variance changes with time, and so the sensitivity of the antenna in that frequency band.
In order to optimize the detection we should use a Wiener filter that gives a gain proportional to the (quadratic) SNR. This however changes the spectral shape of the signal, so the work of the spectral filter is affected. So, as a first step, we use a filter that depends only on the noise, supposing constant the signal.

This is accomplished by

[gw nois]=ps_wiener(g,thr,source)

```
-    g       gd with time series data, as obtained by pss_band_recos
-    thr     cr threshold (typically 4.5)
-    source  source (if present); if source=-1 -> whitening
-
-    gw      filtered gd
-    nois    standard deviation of the noise
```

It is also possible to create "whitened" data.

On the created gw gd, we perform athe power spectrum (with the highest resolution).

Spectral filter

Check the value with distribution

Some miscellanea Snag utilities for known source

```
function [lfftout dtout]=bandrecos_check(dtout0,filein)
% BANDRECOS_CHECK  checks for the best parameters for pss_bandrecos
%
%   dtout0   output preferred sampling time
%   filein   reduced band sbl file
```

For the choice of the lfftout pss_bandrecos parameter. Shows many other parameters.

```
function g=sds_bandextr(file,t,band,dt,gdout)
% SDS_BANDEXTR  extracts a band from an sds stream; creates a gd and a
new unique sds
%        good for very narrow bands
%    LIMITATION: the sds are supposed to contain a single channel
%
%     g=sds_bandextr(file,t,band,dt,lfftout)
%
%   file     the first sds file or list (or 0 -> interactive choice)
%            the list is used in case of more decades. It is created by
%                 dir /b/s  > list.txt
%            and then edited taking only the first file of the each
decade, as
%
O:\pss\virgo\sd\sds\VSR2\sds_h_resh\deca_20090707\VIR_V1_h_4096Hz_20090
707_131945_.sds
%
O:\pss\virgo\sd\sds\VSR2\sds_h_resh\deca_20090717\VIR_V1_h_4096Hz_20090
717_010625_.sds
%
O:\pss\virgo\sd\sds\VSR2\sds_h_resh\deca_20090728\VIR_V1_h_4096Hz_20090
728_002625_.sds
%
O:\pss\virgo\sd\sds\VSR2\sds_h_resh\deca_20090807\VIR_V1_h_4096Hz_20090
807_002625_.sds
%
%   t        [tinit tfin] or 0 -> all
%   band     [frmin frmax]
%   dt       output sampling time
%   gdout    name of the output gd (in absence a default name)
```

Extracts a (narrow) band of signal from a collection of sds files (also for more decades).

```
function [out deld]=rough_clean(in,miny,maxy,nw)
% ROUGH_CLEAN rough cleaning of array or gd
%
%    [out deld]=rough_clean(in,miny,maxy,Dt)
%
%   in           input array or gd
%   miny,maxy    permitted interval
%   nw           window (in samples; def 4)
```

Cleans a gd (or an array) for burst disturbances.

```
function gout=rescale_gd(gin,newscalex,newscaley)
% RESCALE_GD  rescales the abscissa and ordinate of a gd
%
%   newscalex   [a b]
%   newscaley   [a b] (if present)
```

Rescaling of x and y units for gds. Asimilar function is present also for gd2s.

```
function [dop del]=gd_dopplerfromsfdb(tim,vv,pp,source,cont)
% GD_DOPPLERFROMSFDB computes the percentual doppler shift and the delay
%                   from the data in the sfdb files
%
%  Extract vv,pp,tim for example by
%    [g vv pp tim]=pss_band_recos(vela,'pulsar_3.sbl',1024);
%
%   vv,pp,tim    velocity, position and time
%   source       source structure
%   cont         = 0 -> begins from the time 0 of the first day (default)


function p092vbl(piafile,filout)
%
%   p092vbl(piafile,filout)
%
% p09 format:
%
%     Header
% nfft      int32
% sfr       double (sampling frequency)
% lfft2     int32 (original length of fft divided by 2)
% inifr     double
%
%   Block header
% mjd       double
% npeak     int32
% velx      double (v/c)
% vely      double (v/c)
% velz      double (v/c)
% posx      double (x/c)
% posy      double (y/c)
% posz      double (z/c)
%
%   Short spectrum (in Einstein^2)
% spini     double
% spdf      double
% splen     int32
% sp        float (splen values)
%
%     Data (npeak times)
% bin       int32
% ratio     float
% xamed     float (mean of H)
```

```
function conv_p09_conc(folder,filelist)
%CONV_P09_CONC  converts from p09 to vbl and concatenates
%
%   folder      folder containing the decades
%   filelist    file list file (in folder)
%
%
% to obtain the list, do "dir /s/b > list.txt" and edit to arrive at
%
% \deca_20070607\pm_VSR1_20070607-1.p09
% \deca_20070607\pm_VSR1_20070607-2.p09
% \deca_20070607\pm_VSR1_20070607-3.p09
% \deca_20070607\pm_VSR1_20070607-4.p09
% \deca_20070607\pm_VSR1_20070607-5.p09
% \deca_20070617\pm_VSR1_20070617-1.p09
% \deca_20070617\pm_VSR1_20070617-2.p09
% \deca_20070617\pm_VSR1_20070617-3.p09
%
% (without blank lines)
% the list is automatically sorted by the function.
```

Theory and simulation

Snag pss gw project

PSS detection theory

Sampled data simulation

The basic periodic simulation function is

- **sim_sds(sim_str,fdb_str,doptab)** , that creates one or more sds data files. It is based on two structures:
  - **sim_str** , a simulation structure with elements
    - type = 0 stationary, 1 non-stationary
    - nss non-stationarity structure (if type=1)
    - ant antenna structure (only for for signal simulation)
    - sour source structure (only for for signal simulation)
    - lfft fft length for simulation
    - t0 initial time (mjd)
    - dt sampling time (s)
  - **fdb_str** , a file database structure, with elements
    - folder database folder
    - head filename header (p.es. 'VIR_hrec_')
    - tail filename tail (p.es. '_crab')
    - ndat total number of data
    - fndat number of data per file
  - **doptab** , the Doppler table (see Doppler effect page 123).
- **fileout=realsim_sds(sds_in,chn,sim_str,fdb_str,doptab)** , that adds simulated periodic source signal to a real data file. The parameters are:
  - **sds_in** , the input sds file to be used
  - **chn** , the channel number
  - **sim_str** , a simulation structure with elements

- ant antenna structure (only for for signal simulation)
- sour source structure (only for for signal simulation)
- lchunk chunk length for simulation

- **fdb_str** , a file database structure, with elements
  - folder database folder
- **doptab** , the Doppler table (see "Doppler effect", page 123).

These functions, to simulate the periodic source signals, use

- **[d,source,data]=ps_chunk(source,antenna,data,doptab)** , were source, antenna and data are the pss structures and doptab is the correct Doppler table (see "Doppler effect", page 123). The data are simulated in chunks during which the frequency and amplitude is standard (but the chunks can also last a single sample; it is reasonable that last at least one or more seconds). The produced chunks can be added to real data or data simulated with sim_sds (or other).

Fake source simulation

Fake sources can be simulated and added to real data. This is important to define the sensitivity of a set of antenna data.

Fake sources are created with the MatLab function

- **fcand=pss_creasourcefile(sourstr,outfile)** , where

```
sourstr   structure array for source creation; each structure contains:
     .N       number of sources
     .fr      [min max] frequency (at epoch 2000-1-1 0:0)
     .sd1     [min max] first spin down parameter (Hz/day)
     .sd2     [min max] second spin down parameter (Hz/day^2)
     .amp     [min max] amplitude
     .eps     [min max] contents of linear polarization[2]
     .psi     [min max] linear polarization angle
     .alpha   [min max] alpha (equatorial coordinates)
     .delta   [min max] delta  (equatorial coordinates)

  outfile     output file

  fcand       candidate matrix (coordinates are converted to ecliptical)

    all angles are in degrees
    sources are frequency sorted
```

An example is the following:

```
!         Fake Source List
!
! 1 : 100 sources - fr: [50.000,1050.000]  sd1: [0.000,0.000]  sd2: [0.0000,0.000]
!    amp: [0.000100,1.000000]  eps: [0.000000,0.000000]  psi: [0.000000,0.000000]
!    alpha: [0.000000,360.000000]  delta: [-90.000000,90.000000]
! 2 : 400 sources - fr: [50.000,1050.000]  sd1: [0.000,0.001437]  sd2: [0.000,0.000]
!    amp: [0.000100,0.500000]  eps: [0.000000,0.000000]  psi: [0.000000,0.000000]
!    alpha: [0.000000,360.000000]  delta: [-90.000000,90.000000]
!
!   N       freq       sd1         sd2          amp      eps      psi     alpha   delta
!
     1    50.2010 1.3501e-003 0.0000e+000   1.1991e-003 0.0000    0.0      6.78   -6.76
     2    50.6941 0.0000e+000 0.0000e+000   1.4009e-004 0.0000    0.0    200.89   62.12
     3    51.1881 3.8150e-004 0.0000e+000   1.4438e-002 0.0000    0.0    194.19  -14.11
     4    51.3515 0.0000e+000 0.0000e+000   1.2793e-004 0.0000    0.0    128.52   38.01
     5    52.9395 2.3869e-004 0.0000e+000   4.6262e-001 0.0000    0.0     10.29  -32.71
     6    53.0087 0.0000e+000 0.0000e+000   1.3098e-003 0.0000    0.0    212.45  -34.62
     7    53.6771 1.3127e-003 0.0000e+000   8.2358e-002 0.0000    0.0    273.64   51.68
     8    56.0266 7.3225e-004 0.0000e+000   2.1763e-004 0.0000    0.0    241.99   28.50
     9    56.5089 3.4526e-004 0.0000e+000   3.9523e-001 0.0000    0.0    316.17   37.88
    10    57.2503 1.4212e-003 0.0000e+000   1.9581e-004 0.0000    0.0    281.76   61.42
    11    60.3573 1.1635e-003 0.0000e+000   1.1067e-002 0.0000    0.0     31.75   -3.80
```

[2] Defined as the difference between the semimajor and the semiminor axis of the normalized polarization ellipse.

```
12    63.6015 4.9812e-004 0.0000e+000   3.2904e-001 0.0000    0.0    127.37    3.55
13    64.0545 1.3731e-003 0.0000e+000   3.7991e-004 0.0000    0.0    235.73  -16.15
```

This is the beginning of a list of 500 sources. There are

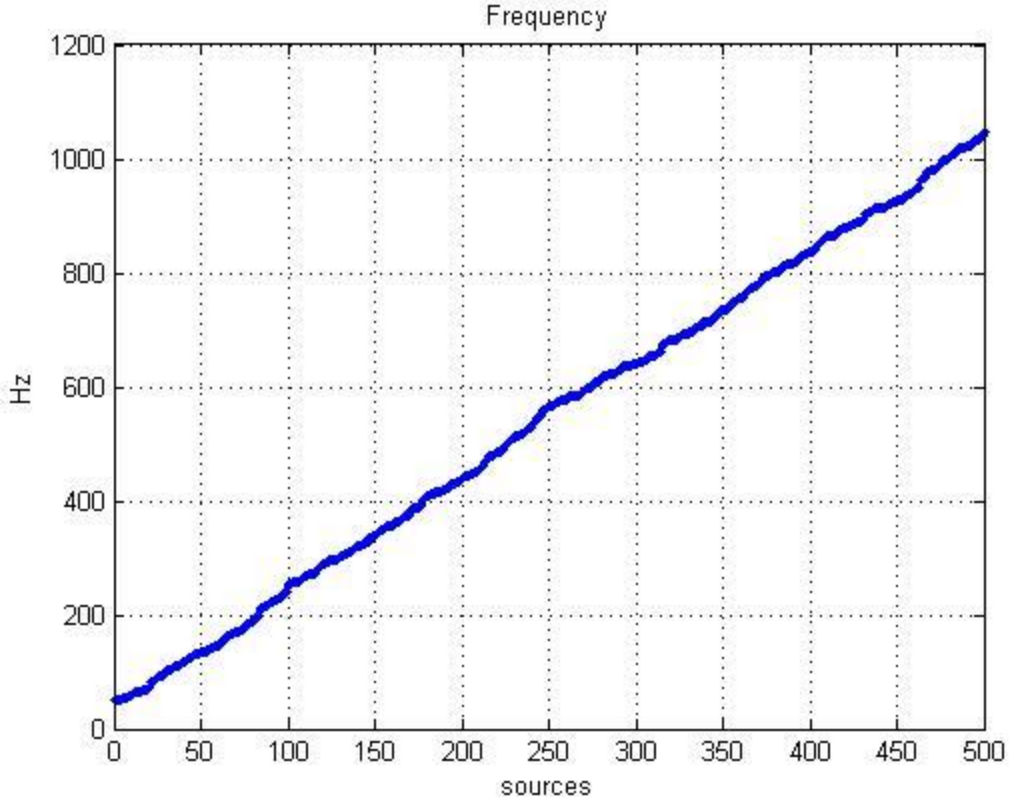
- 3 "frequency" parameters,
- 3 "amplitude and polarization" parameters (the amplitude is normally in units of 10^{-20}, ε is the parameter describing the contents of the linearly polarized power[3], so $\varepsilon = 0$ means circularly polarized radiation, and φ is the angle of the linear polarization with the local celestial meridian)
- 2 position parameters

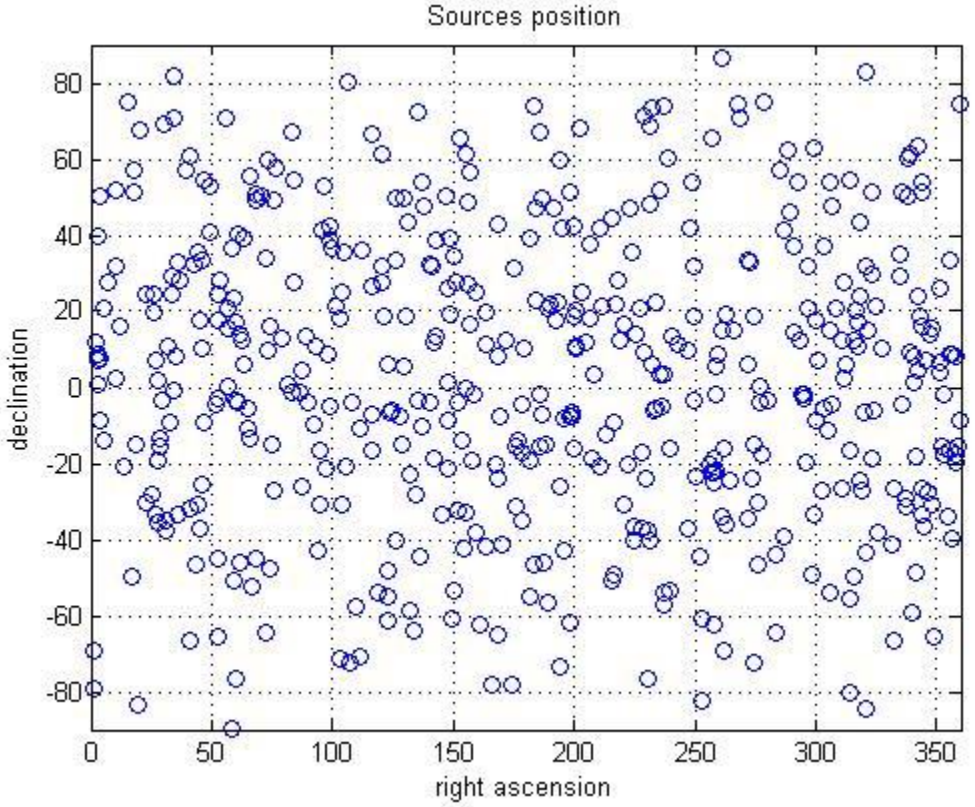
Note that:

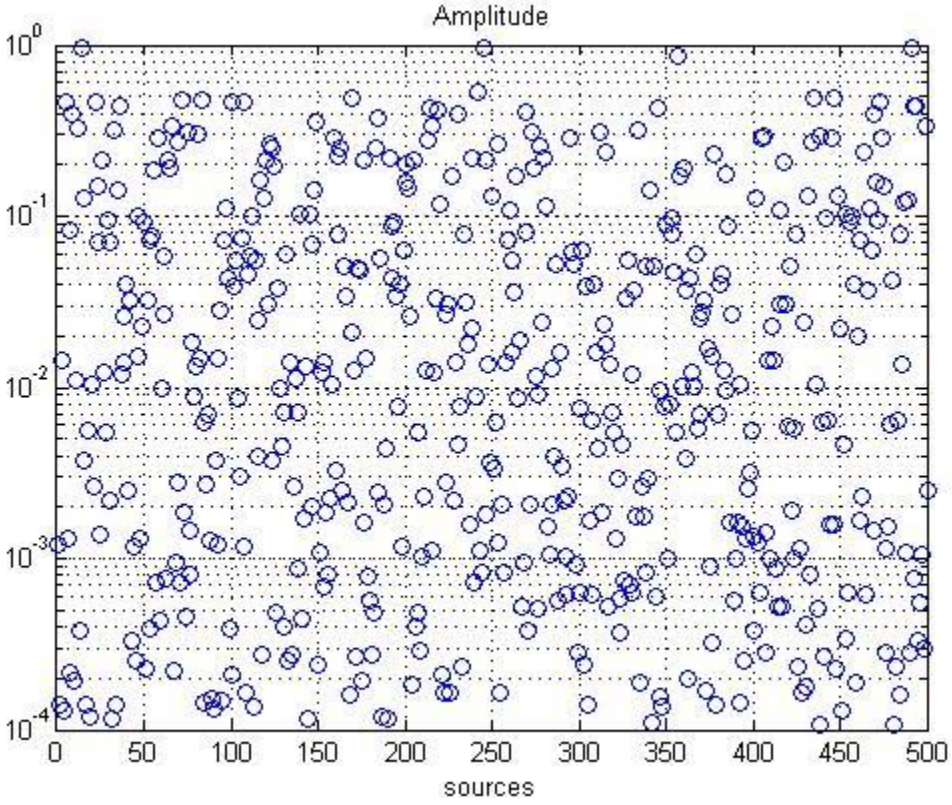
- the frequency is at epoch 1-1-2000 0:00 UT, while the frequency of candidates is referred to the beginning time of the data
- the position is in equatorial coordinates, while the candidates position is in ecliptical coordinates
- the sin-down first order parameter is Hz/day, as for candidates

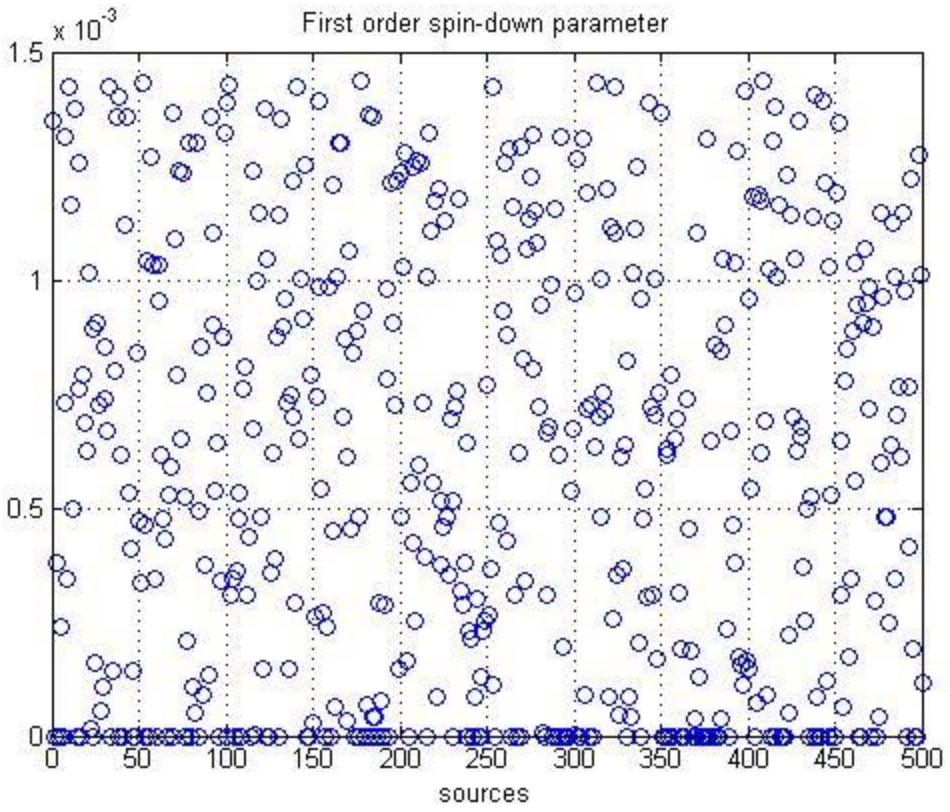
Here are the characteristics of the 500 sources:

[3] Defined as the difference between the semimajor and the semiminor axis of the normalized polarization ellipse.


Frequency
Hz
sources
0
200
400
600
800
1000
1200
0
50
100
150
200
250
300
350
400
450
500


Sources position
declination
right ascension
80
60
40
20
0
-20
-40
-60
-80
0
50
100
150
200
250
300
350


Amplitude
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
0
50
100
150
200
250
300
350
400
450
500
sources



The files are created by an m-file driver called **crea_fakesource_file.m** .

There is also a function to read these files:

➧ **[fcand sour]=pss_readsourcefile(infile)**

infile	output file (interactive if not present)
fcand	candidate matrix (coordinates are converted to ecliptical)
sour	complete matrix

Time-frequency map simulation

The functions to simulate time-frequency spectra are obtained by the same functions that simulate the peak maps, with the input keyword **tfspec** set to 1.

Peak map simulation

There are two simulation functions, one, easier, that can be used for the first incoherent step, when the data chunks have the length of no more than some hours, and another for the subsequent analysis, when the data chunks can be of more than one day.

There are some function to create files to store peak map data:

- **pss_w_pm_0(pm,file)** , that stores the peak map structure **pf** in the file **file**, in a very easy format.

Low resolution simulation

- **pm=pss_sim_pm_lr(ant,sour,pmstr,doptab,nois,level,tfspec)** , where:
  - **ant** is an antenna structure, with elements:
    - **lat** latitude (in degrees)
    - **long** longitude (in degrees)
    - **azim** azimuth
    - **type** antenna type (1 -> bar, 2 -> interferometer)
  - **sour** source structure array; elments used:
    - **a** right ascension (degrees)
    - **d** declination (degrees)
    - **eps** contents of linear polarization[4]
    - **psi** angle of linear polarization
    - **f0** un-Dopplered frequency at start time
    - **df0** coefficient of first power spin-down (Hz/day)
    - **ddf0** coefficient of second power spin-down (Hz/day^2)
    - **snr** signal-to-noise ratio (linear; supposing white noise)
  - **pmstr** peak map property structure
    - **dt** sampling time (s)
    - **lfft** fft length
    - **frin** initial frequency
    - **nfr** number of frequency bins
    - **res** spectral resolution (in normalized units)
    - **t0** initial time (mjd)

[4] Defined as the difference between the semimajor and the semiminor axis of the normalized polarization ellipse.

- **np** number of periodograms
- **thresh** threshold (typically 2)
- **win** window type (0 -> no, 1 -> pss);

- **doptab** Doppler table (see "Doppler effect", page 123)
  table containing the Doppler data (depends on antenna and year) (a matrix (n*4) or (n*5) with:
  - **first column** containing the times (normally every 10 min)
  - **second col** x (in c units, in equatorial cartesian frame)
  - **third col** y
  - **fourth col** z

- **nois** a pmstr.np array with noise levels, in standard deviations;
  if the dimension is not exact, the value 1 is given for all the periodograms

- **level** simulation level:
  - **1** no sid modulation, direct frequency computation, res=1
  - **2** sid modulation, direct frequency computation, res=1
  - **3** no sid modulation, fft frequency computation
  - **4** sid modulation, fft frequency computation

- **tfspec** if = 1, time-frequency spectrum, otherwise only peak map; default 0

Output peak map structure:

- **pm** output peak map structure; elements:
  - **np** number of periodograms
  - **frin** initial frequency
  - **nfr** number of frequency bins
  - **dt** sampling time (s)
  - **lfft** fft length
  - **dfr** frequency bin width
  - **res** spectral resolution (in normalized units)
  - **t0** initial time (mjd)
  - **thresh** threshold (typically 2)
  - **win** window type (0 -> no, 1 -> pss);
  - **t(:)** periodograms time
  - **v(:,3)** periodograms detector velocity
  - **PM** peak map (sparse matrix) or t-f spectrum (matrix)

High resolution simulation

Candidate simulation

[MatLab environment]

The basic candidate simulation function is

- **crea_pssfakecand**, that creates a candidate database. The folder structure should exist. It can be copied from the template that exists in the metadata sub-directory. The input data are:
  - **dircand**, the candidate root directory, containing the folder structure (containing up to 2000 files in 200 folders, grouped in 20 parent folders
  - **N**, the number of candidates to create
  - **band**, wich band (1,2,3 or 4)
  - **pss_cand_head**, pss candidate file header structure and simulation parameters

This function (no return values) can be launched by the m file **batch_fakecreation** (to be edited), that creates two pss candidate databases.

The creation of a pss database of 10^8 candidates takes about 7 minutes on a 3GHz two-cpu computer.

Time and astronomical functions

[MatLab environment]

Time

In Snag there is a number of time conversion functions.

The basic time used in Snag is MJD (Modified Julian Date). Other time used are TAI and GPS time; the form of time (normally UTC time) is also string or vector.

- **t=s2mjd(str)** and **str=mjd2s(mjd)** (**str=mjds2s(mjd)** for multiple operations), converts string time to mjd (modified julian date) and viceversa; example: **mjd=s2mjd('25-Apr-2004 18:44:11'**) produces **mjd = 53120.7806828704**, and **str=mjd2s(mjd)** produces **25-Apr-2004 18:44:11.000004** .

- **str=mjd2s(mjd)** , converts a modified julian date to string time; example:

- **v=mjd2v(mjd)** and **t=v2mjd(v)**, converts a modified julian date to vectorial time ([year month day hour minute second]) and viceversa.

- **tgps=mjd2gps(mjd)** and **mjd=gps2mjd(tgps)** , converts mjd to gps time and viceversa.

- **tai=mjd2tai(mjd)** and **mjd=tai2mjd(tai)** , converts mjd to tai and viceversa.

- **tdt=tai2tdt(tai)** , conversion from TAI to Terrestrial Dynamical Time

- **tsid=sid_tim(mjd,long)** , sidereal time (in hours);

  - **mjd** modified julian date (days)

  - **long** longitude (positive if west of Grenwich; degrees)

Astronomical coordinates

- **[ao,do]=astro_coord(cin,cout,ai,di)** , astronomical coordinate conversion, from cin to cout. Angles and tsid are in radiants. Local tsid and latitude is needed for conversions to and from the horizon coordinates.
  - **cin** and **cout** can be

'horizontal'	azimuth, altitude
'equatorial'	celestial equatorial: right ascension, declination
'ecliptical'	ecliptical: longitude, latitude
'galactic'	galactic longitude, latitude

epsilon = 23.4392911 deg is the aberration to right asc. and declination if they are referred to the standard equinox of year 2000.
(epsilon = 23.4457889 deg, if they are referred to the standard equinox of year 1950.)

Source and Antenna structures

All the functions that need antenna or source information, use the following structures:

- **source structure** (interactive function **sour=i_source**)
  - **a** right ascension (degrees; at pepoch)
  - **d** declination (degrees; at pepoch)
  - **v_a** velocity r.a. (marcs/y)
  - **v_d** velocity dec. (marcs/y)
  - **eps** contents of linear polarization[5]
  - **psi** angle of linear polarization (respect to the source meridian)
  - **f0** frequency (at fepoch)
  - **df0** frequency first derivative (epoch 0) (frequency variation Hz/s)
  - **ddf0** frequency second derivative (epoch 0) (df0 variation Hz/s^2)
  - **snr** signal-to-noise ratio
  - **pepoch** position epoch
  - **fepoch** frequency epoch

- **antenna structure** (interactive function **sour=i_antenna**)
  - **type** bar (1), interferometer (2),…
  - **lat** latitude (degrees)
  - **long** longitude (degrees)
  - **heig** heigth (m)
  - **azim** azimuth (degrees)
  - **incl** inclination (degrees)

[5] Defined as the difference between the semimajor and the semiminor axis of the normalized polarization ellipse.

Doppler effect

The computation of the motion of the Earth respect to the Solar System Barycenter is computed by pss_astro, an adaptation and enhancement of a code from JPL and NOVAS software. Among the other possible uses of pss_astro, there is the production of a table, depending on the location of the antenna and the year, that contains the velocity vector of the detector at certain times. The program, in C, is **crea_table**. For a given detector and a given time interval, expressed in mjd, it gives an output file with the following information (1 minute step):

- detector position vector **p** (in light s) in rectangolar Equatorial J2000 coordinates referred to SSB
- velocity vector **v** (normalized to c) in rectangolar Equatorial J2000 coordinates referred to SSB
- frequency variation, deinstein, due to the relativistic Einstein effect

For a given detector and source, emitting at f_s, the observed frequency f_obs is evaluated, using the following formula:

$$f\_obs = f\_s * (1 + \mathbf{p} \bullet \mathbf{v}) - f\_s*deinstein$$

(where **p** is the unitary position vector of the source, in rectangular equatorial J2000 coordinates).

The code asks for the name of the detector. Presently only the detectors Virgo, Explorer and Nautilus are considered, but we plan to insert soon all the others (it is only a question of inserting them in the "detector" structure)

- Detector ? (virgo, explorer, nautilus)
- Initial mjd, final mjd ? (from 1 Jan 1991 (48257)) e.g.: 48300 48500

The output is a file with the name table.dat. This is a typical output:

(Old format - up to December 2009)

An example of the tables is the following (tableVirgo_2000-2010.dat, beginning):

```
virgo: lat=43.631389,long=10.504444,azim=10.00000 (deg)
velx/C,vely/C,velz/C in rect. Equatorial coord., deinstein
Observed frequency at the detector = source_freq*(1-(source_pos x vel/C) - deinstein)

   51544.00000000  -0.000100557372253  -0.000016371087845  -0.000006927597163  0.000000000335206537
   51544.00694444  -0.000100537101901  -0.000016427927612  -0.000006932417453  0.000000000335208710
   51544.01388889  -0.000100514848156  -0.000016483926814  -0.000006937237591  0.000000000335210877
   51544.02083333  -0.000100490649671  -0.000016538999573  -0.000006942057575  0.000000000335213040
   51544.02777778  -0.000100464548820  -0.000016593061781  -0.000006946877404  0.000000000335215197
   51544.03472222  -0.000100436591616  -0.000016646031264  -0.000006951697077  0.000000000335217350
```

(New format - since December 2009)

An example of the tables is the following (table20-virgo.dat, beginning):

```
virgo: lat=43.631413,long=10.504497,azim=19.432600 (deg)
Rectangular equatorial: posx,posy,posz in light seconds , velx/C vely/C velz/C deinstein
    51544.00000000000 -8.76624028679088240 8e+01  4.42321634805643953e+02  1.91849332828605611 2e+02 -
1.00559422425304328 1e-04 -1.63649627152873732 6e-05 -6.92708151150485586 5e-06  0.00000000033520630 4
    51544.00694444445 -8.77227326052296518 8e+01  4.42222327386092786 1e+02  1.91845175133587105 2e+02 -
1.00539366315770706 7e-04 -1.64218872766155840 1e-05 -6.93190181758949744 4e-06  0.00000000033520847 7
    51544.01388888889 -8.77830497108742093 8e+01  4.42212457381923968 6e+02  1.91841014546431353 0e+02 -
1.00517322899616157 2e-04 -1.64779805556586370 6e-05 -6.93672197173849772 8e-06  0.00000000033521064 6
    51544.02083333334 -8.78433530037457472 9e+01  4.42202553992728837 8e+02  1.91836851067230014 7e+02 -
1.00493330428677883 4e-04 -1.65331564932071486 8e-05 -6.94154197248499385 9e-06  0.00000000033521280 9
    51544.02777777778 -8.79036413268207610 4e+01  4.42192617794295244 9e+02  1.91832684696075404 0e+02 -
1.00467430882295594 7e-04 -1.65873307854984752 5e-05 -6.94636181851126684 6e-06  0.00000000033521496 7
    51544.03472222222 -8.79639135453206364 4e+01  4.42182649413095703 0e+02  1.91828515433340413 7e+02 -
1.00439669888862836 2e-04 -1.66404210420511724 9e-05 -6.95118150832786346 0e-06  0.00000000033521712 0
    51544.04166666666 -8.80241685650393463 9e+01  4.42172649522414133 1e+02  1.91824343278559666 7e+02 -
1.00410966310433863 3e-04 -1.66923469575205672 0e-05 -6.95600104156836826 1e-06  0.00000000033521926 8
    51544.04861111111 -8.80844053102019870 5e+01  4.42162618845065083 0e+02  1.91820168232106965 4e+02 -
1.00378763762569024 7e-04 -1.67430304404773660 2e-05 -6.96082041705200292 0e-06  0.00000000033522141 1
    51544.05555555555 -8.81446227416815730 7e+01  4.42152558149340393 4e+02  1.91815990294077181 5e+02 -
1.00345727300373100 2e-04 -1.67923957950307130 3e-05 -6.96563963407782395 7e-06  0.00000000033522354 9
    51544.06250000000 -8.82048198549413379 4e+01  4.42142468248206512 3e+02  1.91811809464556552 7 6e+02 -
1.00311046519056980 4e-04 -1.68403698264286242 6e-05 -6.97045869210266302 3e-06  0.00000000033522568 2
    51544.06944444445 -8.82649956819695233 9e+01  4.42132349997748008 3e+02  1.91807625743667500 7e+02 -
1.00274783874623400 2e-04 -1.68868201683489839 2e-05 -6.97527759074196123 1e-06  0.00000000033522781 0
```

Notes and observation:

1. this code is based on the PSS_astro library, whose documentation is given in the PSS_astro_UG.doc and PSS_astro_PG.doc
2. it uses the JPL ephemeris file DE405 and files from IERS for fine corrections of the time and nutation. These fine corrections (use of UT1 and not UTC, application of corrections to the nutation angles DPsi and DEpsilon) are provided by IERS only up-to-date, with the file eopc04.62-now. In case these files are not present for the time lag (or part of it) provided by the user, then the code does not use these fine corrections and a message appears on the screen and also in the file which is created.
3. the deinstein corrections is at a level less than one part on one million.
4. As shown with details in the documentation, the Einstein effect is only a small correction to the final Doppler effect, but, given the fact that it can be evaluated using only information on the detector, that is it does not depend on the source position, we have decided to store also this information. The Einstein effect gives a contribution which is -roughly speaking- 5 orders of magnitude lower compared to the revolution and 3 orders of magnitude lower compared to the rotation. On the contrary, the Shapiro effect (which is even smaller) depends also on the source and thus cannot be evaluated at this stage. There is a function in the PSS_astro code to add the Shapiro effect, if a very high precision is needed. The Shapiro effect gives a contribution which is -roughly speaking- 3 orders of magnitude lower compared to the Einstein effect.

The time is **TT** (Terrestrial Time) in the form of **MJD**. Interpolation from a table at 10 minutes (one year about 10 MB, in matlab format 3 MB), gives rise to an error on each component less than 10^-13, so obtaining a maximum relative error of the order of 10^-9.

The problem for the exact computation of the Doppler effect is that it cannot be done in advance, because the future Earth rotation is not completely known, so there is an error on this component (that is about 0.01 of the total motion), that is, for the position, an error of about 300 m (or 1 μs) per each leap second.

The Doppler table used by the software is a [8 x n] matrix, with the first column containing the times (in TT days), then 3 columns containing the components of the position (in light seconds) and then 3 components with the detector velocity divided by c. The eighth column contains the Einstein effect (gravitational redshift), so

$$f\_obs = f\_s * (1 + \mathbf{p} \bullet \mathbf{v} - deinstein)$$

The Doppler table is produced by the function

- **doptab=read_doppler_table(file,subsamp,fileout)** , with

- file file created by crea_table
- subsamp subsampling (one every...)
- fileout output file (can be not present)

The following function puts the Doppler table (the x, y, and z component of the velocity of the detector in single precision) in an dds file (or sds, in 4-byte precision)

- **doptab2dds(doptab,sdsfile,capt)**, (or doptab2sds), with

  - doptab the Doppler table
  - sdsfile the sds file
  - capt the caption of the sds file

These sds files (that are tiny) can be read to produce the matrix doptab; the procedure to do it is:

- **doptab=doptab_from_dds(subsamp,tim,file)** (or doptab_from_sds), with

  - subsamp the subsampling factor
  - tim [min max] time (mjd)
  - file the dds file (like **virgo_doptab.dds** of 60 MB)

Normally the Doppler tables are computed and stored for long periods (e.g. 2000-2020), but for practical purposes (typically for spline interpolation) it is more practical and fast to use shorter tables. This is accomplished by extracting a sub-table from a big table by

- **subdoptab=reduce_doptab(doptab,tmin,tmax)** , were doptab is the original table, tmin and tmax the time interval of the sub-table.

The following function is a simple use of **doptab**:

- **dop=gw_doppler(doptab,source,t)** , computes the percentage Doppler shift for the Earth motion. It works with a single time or with a single source

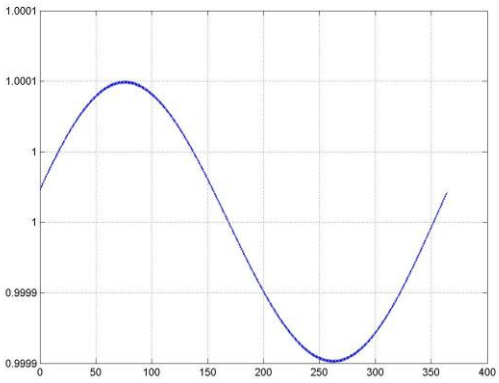
  - **doptab** table containing the Doppler data (depends on antenna and year)
    (a matrix (n*4) or (n*5) with:
    1st column containing the times (normally every 10 min)
    2nd col x (in c units, in equatorial cartesian frame)
    3rd col y
    4th col z
    5th col vx (in c units, in equatorial cartesian frame)
    6th col vy
    7th col vz
    8th col de-einstein)
  - **source** pss structures or a double array (n*2) with
    first col the sources alpha (in deg)

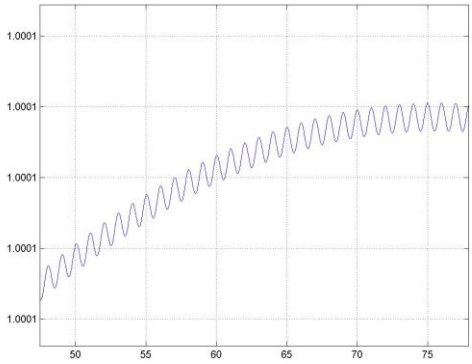
second col the source delta (in deg)

- **t** time array TAI (in mjd days)

This function uses the tables created by pss_astro, interpolating with **spline()**.

Here is the results for 2003:





There is also another function that computes the Doppler effect,

- **dop=gw_doppler1(v,source)** , that uses the velocity vector of the detector and the source.

Another example is

- **[v_x,v_y,v_z]=v_detector(doptab,t)** , that creates the three arrays containing the three components of the detector velocity at the times of the array t.

Sidereal response

Because of the radiation pattern of the antenna, the response to a gravitational source varies depending on the sidereal hour. A number of functions dealing with these problem are developed:

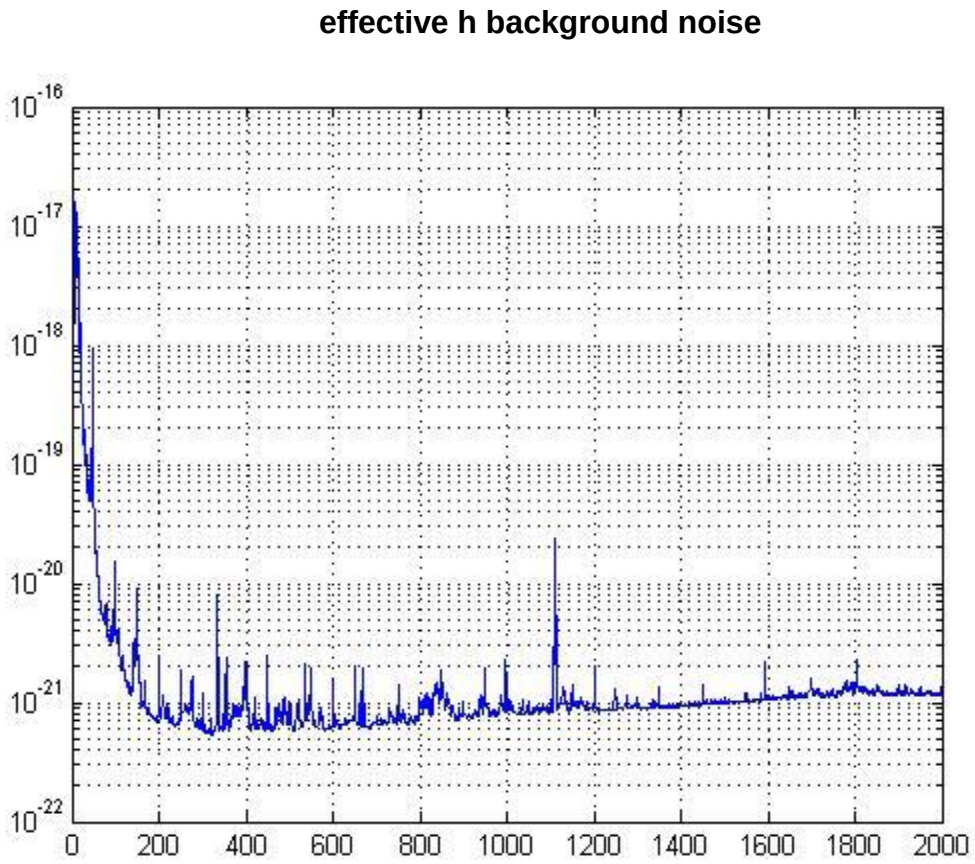
- **sr=sid_resp(antenna,source,n)** , gives the sidereal response in energy; the parameters are:
  - **antenna**, an antenna structure
  - **source**, a source structure
  - **n** , the number of points in a sidereal day

Other analysis tools

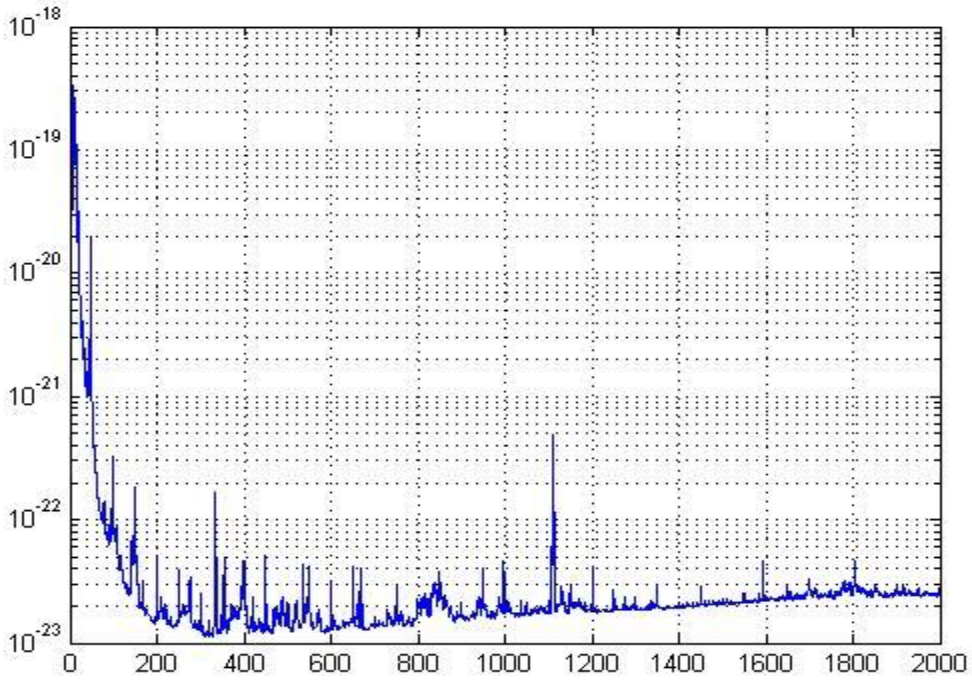
Sensitivity evaluation

- **[h_eff,sens,dist,med]=effect_bg(chn,x,y)** from a short spectra file (normally in sfdb run folders of pss), computes the effective h background noise, the pss sensitivity, the "horizon" and the mean (for each spectrum) in 3 bands.

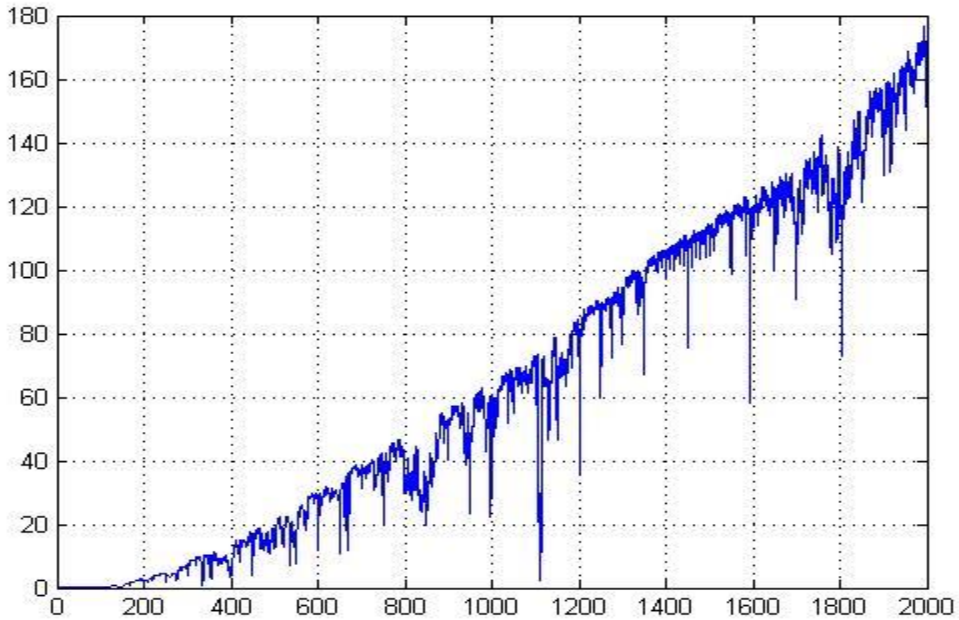
Here are the plots for C7:



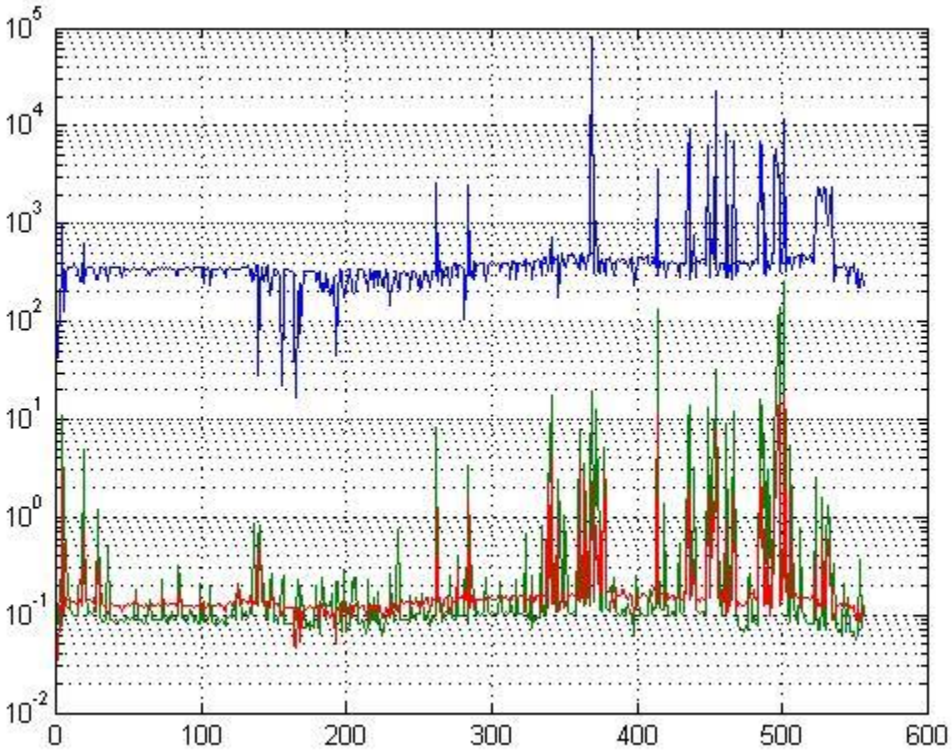
pss sensitivity



Horizon (pc)



Mean of bands in each spectrum



Sidereal analysis

Here we present some procedure to detect circadian and sidereal periodicity in the noise data.

Data preparation

We start from the sfdb data (also containing only the very short spectra, in the form of mean of periodograms). Then create the list of the SFDB09 file with

dir /b/s > list.txt

and edit it in the standard way. In Matlab execute

iok=piavespet2sbl(list,filesbl)

Then, from the created sbl file, create the subband gd2s by a script like e.g.

```
% calc_cent_rawExpl

for i = 1:7
    str=sprintf('Expl_raw07_%02d',i);
    n1=num2str((i-1)*25);
    n2=num2str(i*25);
    eval([str '=sbl2gd2_sel_phys(''expl07.sbl'',1,[0 60000 1],['
n1 ' ' n2 ' 1])'])
    eval(['save ' str ' ' str])
    eval(['clear ' str])
end
```

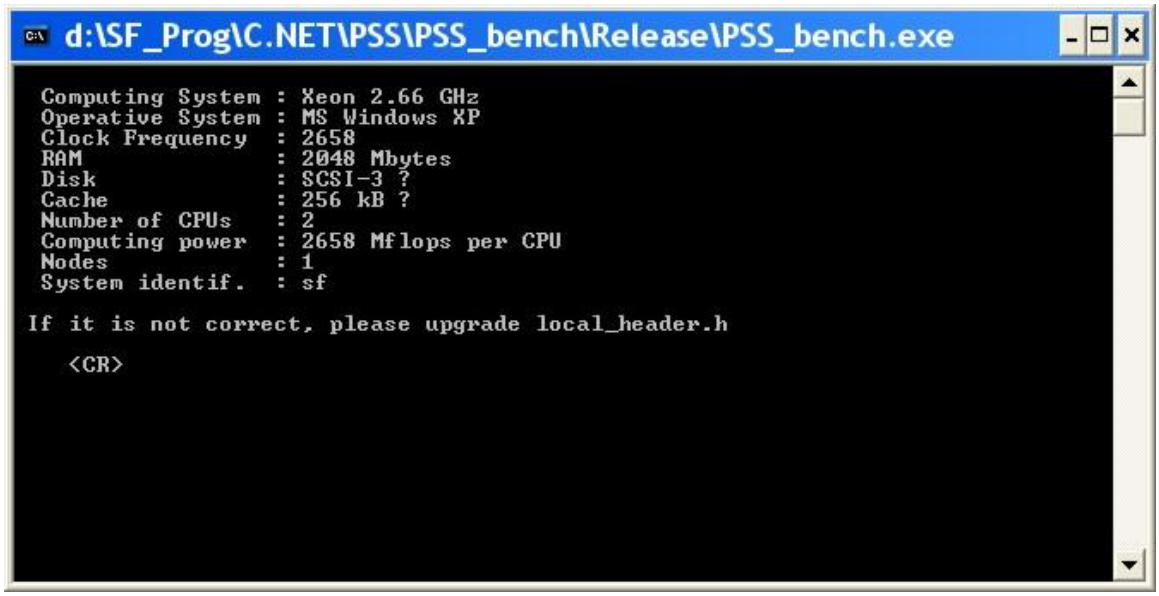
This set of files are used for all analyses.

Tests and benchmarks

The PSS_bench program

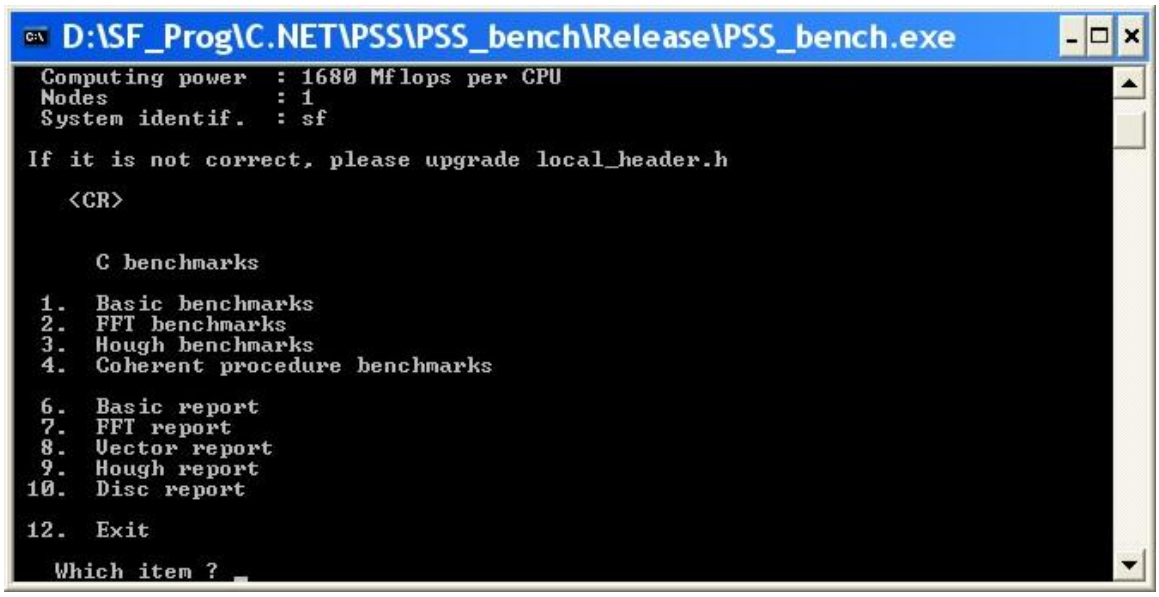
The interactive program

The program starts from the command console. At the beginning the computer information appears

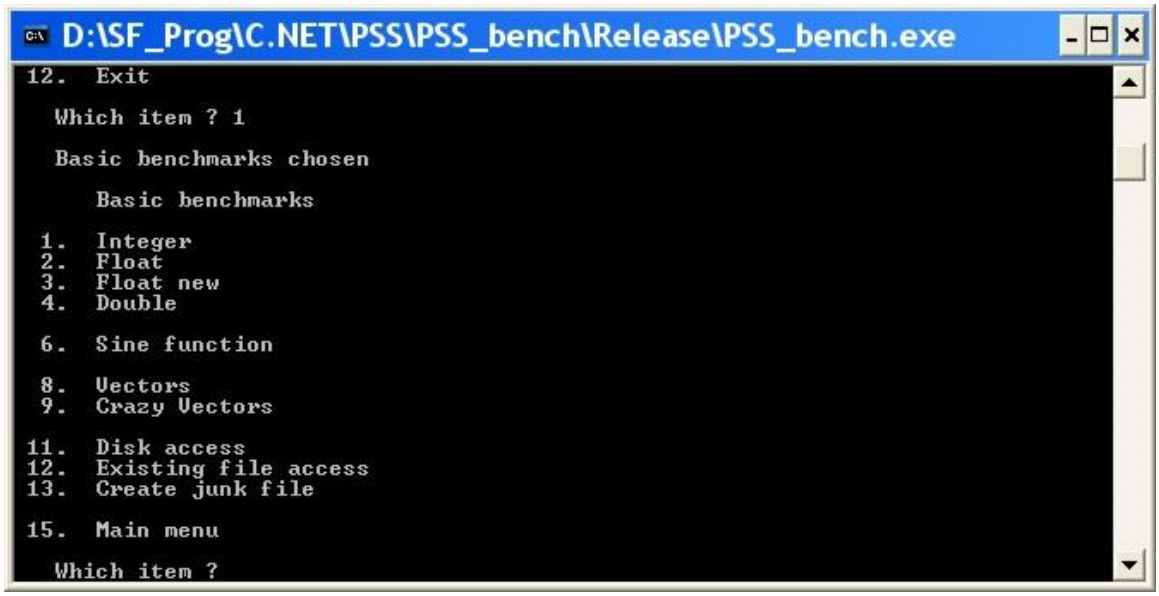

d:\SF_Prog\C.NET\PSS\PSS_bench\Release\PSS_bench.exe
Computing System : Xeon 2.66 GHz
Operative System : MS Windows XP
Clock Frequency : 2658
RAM : 2048 Mbytes
Disk : SCSI-3 ?
Cache : 256 kB ?
Number of CPUs : 2
Computing power : 2658 Mflops per CPU
Nodes : 1
System identif. : sf
If it is not correct, please upgrade local_header.h
<CR>

The computer information resides in a header named **local_header.h** and should be changed anytime that the benchmark is installed on a new computer. It should be re-compiled and linked for different configuration (important is the **no_optimization**).

Then the main menu appears. It shows the different classes of benchmarks that can be run.



Then the menu of the particular class of benchmark appears. For example, for the basic benchmark:



The benchmarks started from the main menu can be also reports.

The reports

Basic report

```
  PSS_bench report on Tue Feb 17 15:07:17 2004


                Computing System : Xeon 2.66 GHz
                Operative System : MS Windows XP
                Clock Frequency  : 2658
                RAM              : 2048 Mbytes
                Disk             : SCSI-3 ?
                Cache            : 256 kB ?
                Number of CPUs   : 2
                Computing power  : 2658 Mflops per CPU
                Nodes            : 1
                System identif.  : sf

 Comment: ...
             Lower values are better results

                    Basic tests

Integer: rough1,rough2,sum,product
11.615460,16.187220,4.598340,27.005280
Float  : rough1,rough2,sum,product
13.290000,6.219720,1.674540,1.249260
Double : rough1,rough2,sum,product 19.934999,7.894260,-
0.850560,-0.398700

Sines  : 203.337006

Vectors: length 100000 -> rough,sum = -7.043700,19.084440
Crazy  : length 100000 -> no crazy,crazy =
4.173060,40.667400

                     FFT tests

Four1  : 54.664391 (length 1048576)

                    Hough tests

LUT    : 12.260115 (nalpha, ndelta = 720, 360)
```

FFT report

PSS_bench FFT (fftw) report on Tue Feb 17 15:07:42 2004

```
            Computing System : Xeon 2.66 GHz
            Operative System : MS Windows XP
            Clock Frequency  : 2658
            RAM              : 2048 Mbytes
            Disk             : SCSI-3 ?
            Cache            : 256 kB ?
            Number of CPUs   : 2
            Computing power  : 2658 Mflops per CPU
            Nodes            : 1
            System identif.  : sf

 Comment: ...
          Lower values are better results

      length    efficiency loss

       1024              4.28     (8.2474e-005 s/fft)
       2048              3.93     (1.6667e-004 s/fft)
       4096              3.38     (3.1250e-004 s/fft)
       8192              3.12     (6.2500e-004 s/fft)
      16384              5.99     (2.5833e-003 s/fft)
      32768              5.59     (5.1667e-003 s/fft)
      65536             11.91     (2.3500e-002 s/fft)
     131072             11.21     (4.7000e-002 s/fft)
     262144             13.18     (1.1700e-001 s/fft)
     524288             10.41     (1.9500e-001 s/fft)
    1048576             12.48     (4.9250e-001 s/fft)
    2097152             10.09     (8.3600e-001 s/fft)
    4194304             10.04     (1.7425e+000 s/fft)
    8388608              9.86     (3.5780e+000 s/fft)
```

PSS_bench FFT (four1) report on Tue Feb 17 17:38:49 2004

```
            Computing System : Xeon 2.66 GHz
            Operative System : MS Windows XP
            Clock Frequency  : 2658
            RAM              : 2048 Mbytes
```

```
            Disk              : SCSI-3 ?
            Cache             : 256 kB ?
            Number of CPUs    : 2
            Computing power   : 2658 Mflops per CPU
            Nodes             : 1
            System identif.   : sf

Comment: ...
             Lower values are better results

     length    efficiency loss

       1024          840.26     (1.6186e-002 s/fft)
       2048          729.80     (3.0927e-002 s/fft)
       4096          535.14     (4.9479e-002 s/fft)
       8192          169.10     (3.3875e-002 s/fft)
      16384            5.99     (2.5833e-003 s/fft)
      32768            5.59     (5.1667e-003 s/fft)
      65536           43.60     (8.6000e-002 s/fft)
     131072           50.34     (2.1100e-001 s/fft)
     262144           54.58     (4.8450e-001 s/fft)
     524288           59.61     (1.1170e+000 s/fft)
    1048576           60.20     (2.3750e+000 s/fft)
    2097152           64.78     (5.3670e+000 s/fft)
    4194304           69.76     (1.2110e+001 s/fft)
    8388608           77.66     (2.8188e+001 s/fft)
   16777216           79.28     (6.0047e+001 s/fft)
```

SFDB

Hough transform

Service routines

Matlab service routines

- i_antenna
- i_source
- i_data
- pss_par
- ipss_par
- source_tab

pss_lib

pss_rog

General parameter structure

All the parameters used for this software are organized in nested structures. Here all these structures are described. Any parent structure can lack some children.

Main pss_ structure

This is the container for the other high level structures. The parameters are classified in 4 **classes**:

0 fixed
1 primary or input
2 derived
3 analysis results
4 other

Structures	Type	Use
const_		Mathematics, Physics and Astronomy constants
source_	may contain arrays	periodic source parameters
antenna_	may contain arrays	detector physical parameters
data_		data parameters
fft_		fft parameters
band_		band description
sfdb_	may contain arrays	short fft data-base parameters
tfmap_	may contain arrays	time-frequency map
tfpmap_	may contain arrays	time-frequency peak map
hmap_	may contain arrays	hough map parameters
cohe_		coherent follow-up parameters
ss_		supervisor parameters
candidate_	may contain arrays	periodic source candidates
event_	may contain arrays	event parameters
computing_		computing parameters

const_ structure

It contains:

constant	class	type	what
pi	**0**		3.14159265358979323846264338327 95
e	**0**		2.71828182845904523536028747135 27
c	**0**		light velocity - 299792458
G	**0**		gravitational constant - 6.67259E-11
deg2rad	**0**		degree to radiants conversion
Eorbv	**0**		Earth orbital velocity
Erotv	**0**		Earth rotational velocity (at the equator)
SY_s	**0**		sidereal year seconds
SD_s	**0**		sidereal day seconds

source_ structure

All the angles are in degrees.

parameter	class	type	what
name	1		
a	1		rigth ascension or ecliptical longitude (deg)
d	1		declination or ecliptical latitude (deg)
v_a	1		variation of a (marcs/y)
v_d	1		variation of d (marcs/y)
pepoch	1		position epoch
eps	1		contents of linear polarization [6]
psi	1		polarization angle; psi < 0 clockwise rotation (also if eps = 0) and psi = psi+90
t00	1		f0 epoch (typically 1-1-2000)
f0	1		initial (original) frequency
df0	1		initial first derivative of the frequency (frequency variation per day)
ddf0	1		second derivative of the frequency (df0 variation per day)
fepoch	1		frequency parameters epoch
h	1		h amplitude
snr	1		signal-to-noise ratio
coord	1	?	0 -> equatorial, 1 -> ecliptical
n	1		number of sources
chphase	4		phase of the last chunk (used by pss_chunk)

[6] Defined as the difference between the semimajor and the semiminor axis of the normalized polarization ellipse.

antenna_ structure

parameter	class	type	what
name	1		
long	1		
lat	1		
azim	1		azimuth
alt	1		altitude over sea level
incl	1		inclination
type	1		
bar_		structure	
itf_		structure	
n	1		number of antennas

data_ structure

parameter	class	type	what
dt	1		sampling time (s)
sf	2		sampling frequency
tobs	1		total observation time days)
t0	1		initial time (mjd)
iniwin	1	double array	starting time of windows
finwin	1	double array	ending time of windows
nwin	1		number of windows
t	4		time (mjd)

fft_ structure

This is a sub-structure used in (or in conjunction with) sfdb_, tfmap_ and tfpmap_ structures. It describes the working band. It can be also used alone.

parameter	class	type	what
len	1		fft length (number of samples)
tlen	2		fft time length
N	1		number of ffts
onev	1		take one fft every...
df	2		frequency bin
res	1		resolution
interl	1		interlacing
wind	1		window type
frin	1		initial frequency
tin	1		initial time
unit	1		unity

band_ structure

This is a sub-structure used in sfdb_, tfmap_ and tfpmap_ structures. It describes the working band. It can be also used alone.

parameter	class	type	what
Bf1	**1**		initial frequency of the full band
Bf2	**1**		final frequency of the full band
f0	**1**		supposed initial unshifted frequency
df0	**1**		f0 first derivative
ddf0	**1**		f0 second derivative
errf0	**1**		(band.f0-source.f0)/fft.df
natb	**3**		"natural" sub-band (working band)
knatb	**1**		widening factor of natural sub-band
bf1	**3**		sub-band initial frequency
bf2	**3**		sub-band final frequency

sfdb_ structure

parameter	class	type	what

tfmap_ structure

parameter	class	type	what

tfpmap_ structure

parameter	class	type	what

hmap_ structure

parameter	class	type	what

cohe_ structure

parameter	class	type	what

ss_ structure

parameter	class	type	what

candidate_ structure

parameter	class	type	what

event_ structure

parameter	class	type	what

computing_ structure

parameter	class	type	what

The Log Files

Any production job produces a log file.

These log files have general standard format. Here are the main features:

- the **name** is **`jobtype_yyyymmdd_hhmmss.log`**
- they are **text files** (ASCII)
- they are structured in
  - **explanatory lines**, starting with "! "
  - **header**, with
    - starting date
    - parameters, a parameter for each line, starting with " `(PAR)` " and then the name of the parameter and its value
    - special parameters, namely arrays or matrices, written in blocks in "user mode". These blocks are marked by a first line with "SPECIAL> label" and a last line with "ENDSPECIAL> label"
  - **body**, with
    - events, starting with "`--> XXX >` ", with `XXX` a 3-character code of the event type
    - partial statistics and résumé, starting with "`>>> XXX >` ", with `XXX` a 3-character code of the stat type
    - errors, starting with "`*** ERROR !` ", followed by a string
  - **footer**, with
    - end date
    - final statistics and résumé

Example of log file:

```
PSS program_name job log file

started at date_and_time_string

! possible explanation line
! (any number, everywhere, starting with "! ")

(PAR) PAR1  xxxxx
(PAR) PAR2  xxxxx
...
(PAR) PARn  xxxxx
INPUT : filein comments
OUTPUT : fileout comments

--> ATT > xxxx1  xxxx2  xxxx3 ....
--> ATT > xxxx1  xxxx2  xxxx3 ....
--> FDS > xxxx1  xxxx2  xxxx3 ....

>>>DSC> xxxx1  xxxx2  xxxx3 ....
>>>VCX> xxxx1  xxxx2  xxxx3 ....

*** ERROR ! ssssss

stop at date_and_time_string

final results
```

There is a collection of function to create log files. It is in pss_serv (a module of pss_lib) and contains:

- `FILE* logfile_open(char* prog)`
- `int logfile_comment(FILE* fid, char* comment)`
- `int logfile_error(FILE* fid, char* errcomment)`
- `int logfile_par(FILE* fid, char* name, double value, int prec)`
- `int logfile_ipar(FILE* fid, char* name, long value)`
- `int logfile_special(FILE* fid, char* label)`
- `int logfile_endspecial(FILE* fid, char* label);`

- `int logfile_input(FILE* fid, char* inpfile, char* comment)`
- `int logfile_output(FILE* fid, char* outfile, char* comment)`
- `int logfile_ev(FILE* fid, char* type, int nvalues, double* values, int* prec)`
- `int logfile_stat(FILE* fid, char* type, int nvalues, double* values, int* prec)`
- `int logfile_stop(FILE* fid)`
- `int logfile_close(FILE* fid)`

Note that, for the functions logfile_par, logfile_ev and logfile_stat, we need not only the values of the parameters for the output, but also the precision, namely

prec	format
0	%g
1	%.3f
2	%.6f
3	%.9f
10	%.6e
100	%.0f

Here is an example of use:

```
void main()
{
	FILE* fid;
	double data[4];
	int prec[4];

	data[0]=123.434;
	data[1]=123.533;
	data[2]=123.67;
	data[3]=123.34;
	prec[0]=0;
	prec[1]=1;
	prec[2]=3;
	prec[3]=10;

	fid=logfile_open("PROVA");

	logfile_comment(fid,"commento 1");
	logfile_par(fid,"ASD",1234.567,0);
	logfile_input(fid,"FILE_IN","CHANNEL 1");
	logfile_output(fid,"FILE_OUT","scratch file");
	logfile_ev(fid,"PYW",4,data,prec);
	logfile_comment(fid,"commento 2");
	logfile_stop(fid);
	logfile_close(fid);
}
```

And this is the created file PROVA_20051230_171452.log :

```
PSS PROVA job log file

started at Mon Jan 30 14:01:57 2006

! commento 1
(PAR) ASD = 1234.57
INPUT : FILE_IN  CHANNEL 1
OUTPUT : FILE_OUT  scratch file
--> PYW > 123.434 123.533 123.670000000 1.233400e+002
! commento 2

stop at Mon Jan 30 14:01:57 2006
```

To read logfiles

Some functions has been developed in MatLab to "read" log files.

Here are some:

- **out=read_log(filout,filin)** produces an output structure out, that contains 5 objects that can be sub-structures or cell arrays, each item of which refers to a log line. The 5 objects are:
  - **com**, a cell array for the comments,
  - **par**, a structure for the parameters,
  - **ev**, a structure for the events,
  - **stat**, a structure for the stats,
  - **err**, a cell array for the errors.

  It shows also the comments and the parameters on the screen and can put them on a file.

- **out=read_log_noev(filout,filin)** , similar to the preceding one, but skipping the events (it can be much faster).

- **[t a out]=read_logtev(filout,filin)** , this is specific for the SFDB creation jobs. It reads the time event found.

- **[t f a out]=read_logfev(filout,filin)** , this is specific for the SFDB creation jobs. It reads the frequency event found.

Example of use of logfile data

For the construction of the C6 SFDB, we have a logfile of 21 MB. The output of read_log_noev is:

```
  File  D:\SF_DatAn\pss_datan\Reports\crea_sfdb_20060131_173851.log

started at Tue Jan 31 17:38:51 2006
 even NEW: a new FFT has started
    PAR1: Beginning time of the new FFT
    PAR2: FFT number in the run
 even EVT: time domain events
    PAR1: Beginning time, in mjd
    PAR2: Duration [s]
    PAR3: Max amplitude*EINSTEIN
 even EVF: frequency domain events, with high threshold
    PAR1: Beginning frequency of EVF
    PAR2: Duration [Hz]
    PAR3: Ratio, in amplitude, max/average
    PAR4: Power*EINSTEIN**2 or average*EINSTEIN (average if duration=0, when age>maxage)
 stat TOT: total number of frequency domain events
 par GEN: general parameters of the run
    GEN_BEG is the beginning time (mjd)
    GEN_NSAM the number of samples in 1/2 FFT
    GEN_DELTANU the frequency resolution
    GEN_FRINIT the beginning frequency of the FFT
    EVT_CR is the threshold
    EVT_TAU the memory time of the AR estimation
    EVT_DEADT the dead time [s]
    EVT_EDGE seconds purged around the event
    EVF_THR is the threshold in amplitude
    EVF_TAU the memory frequency of the AR estimation
    EVF_MAXAGE [Hz] the max age of the process. If age>maxage the AR is re-evaluated
    EVF_FAC is the factor for which the threshold is multiplied, to write less EVF in the log file
stop at Wed Feb  1 12:39:22 2006
```

Parameters

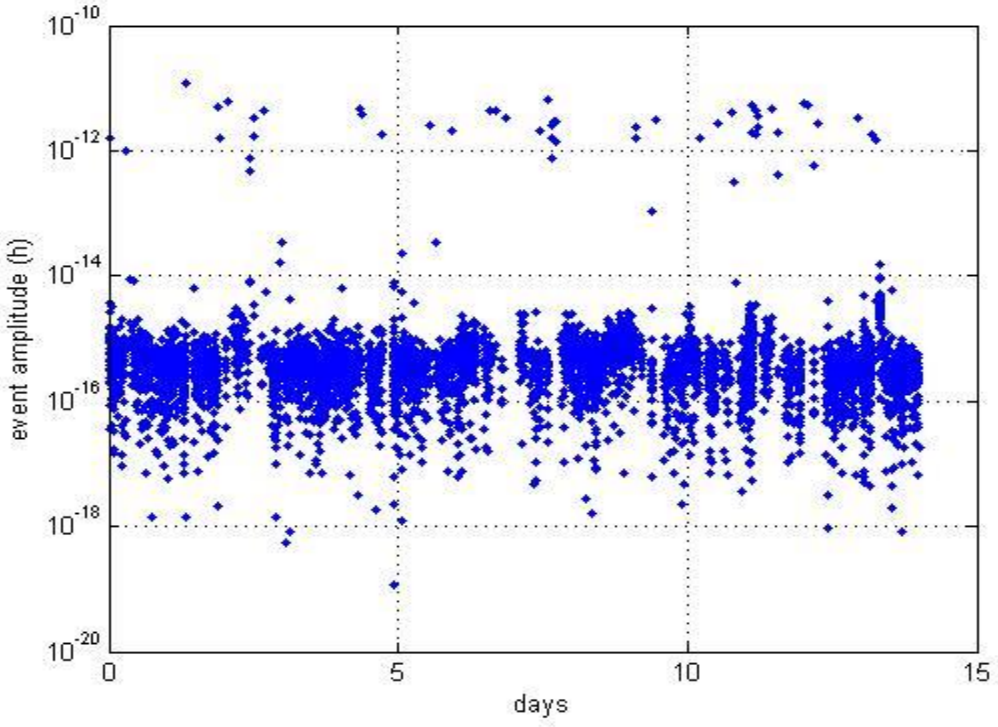
GEN_BEG	53580.583183
GEN_NSAM	2097150.000000
GEN_DELTANU	0.000954
GEN_FRINIT	0.000000
EVT_CR	6.000000
EVT_TAU	600.000000
EVT_DEADT	1.000000
EVT_EDGE	0.150000
EVF_THR	2.500000
EVF_TAU	0.020000
EVF_MAXAGE	0.020000
EVF_FAC	2.000000

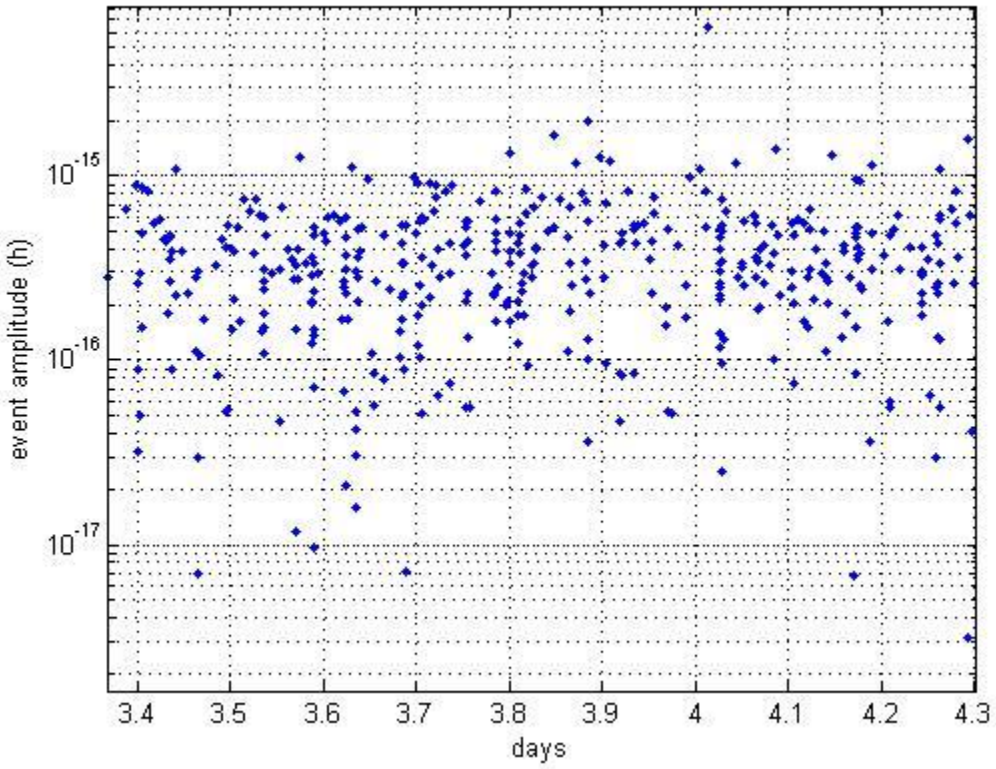
Time events

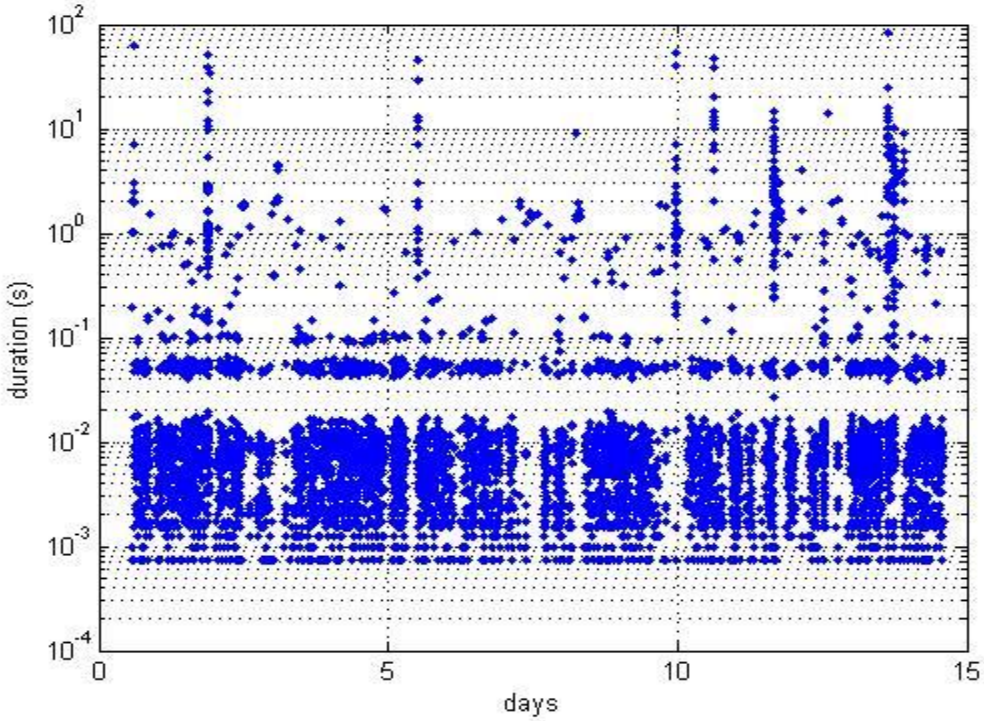
With

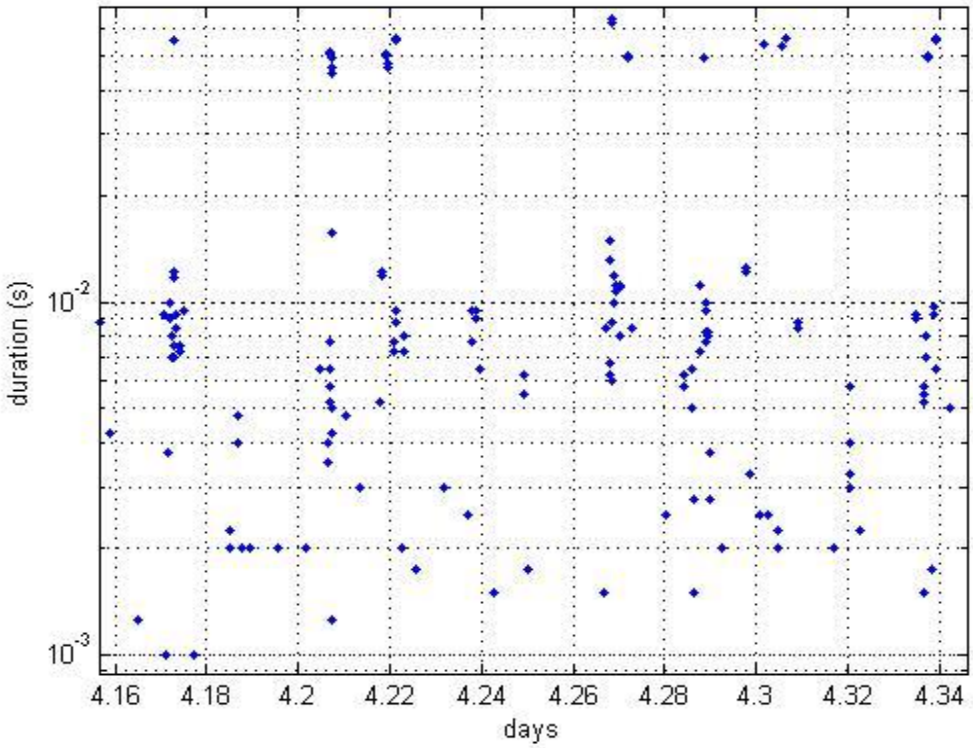
>> [t a d]=read_logtev

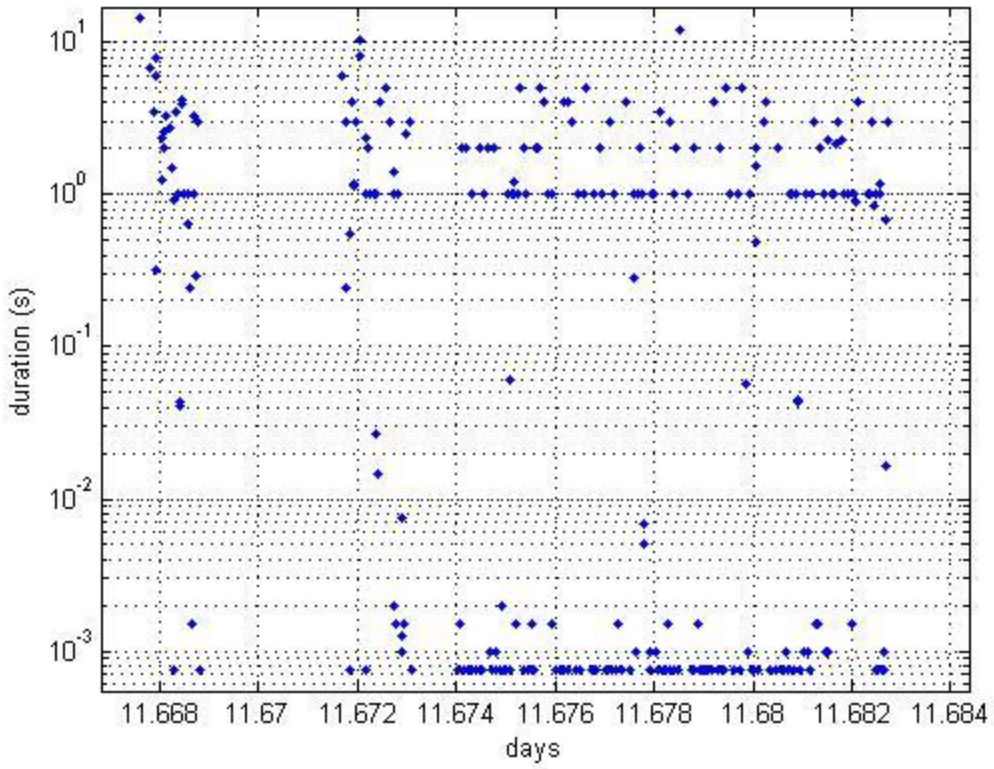
we obtain the 8109 time events in the log. Here is the plot




event amplitude (h)
10^{-15}
10^{-16}
10^{-17}
3.4
3.5
3.6
3.7
3.8
3.9
4
4.1
4.2
4.3
days


duration (s)
days


duration (s)
days

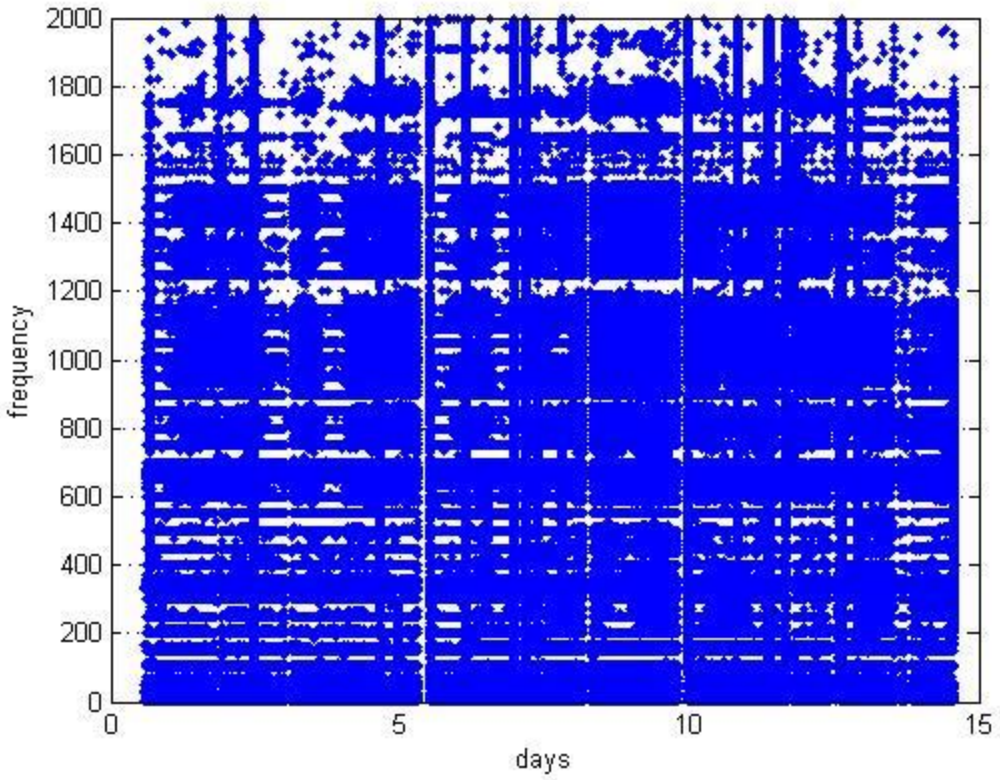


Frequency events

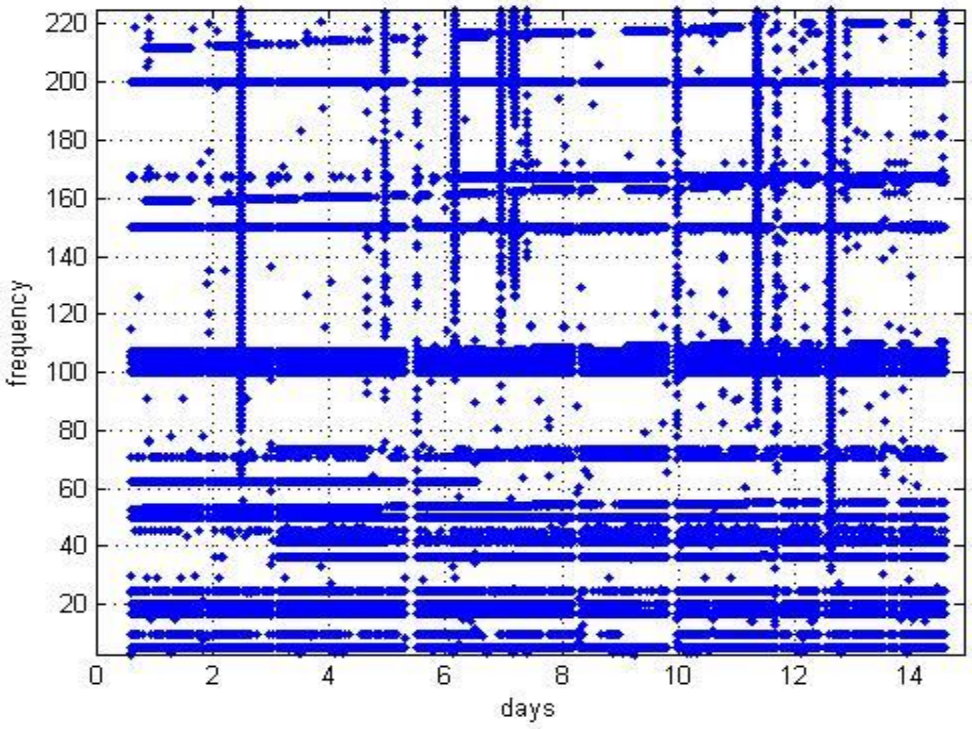
Then, with

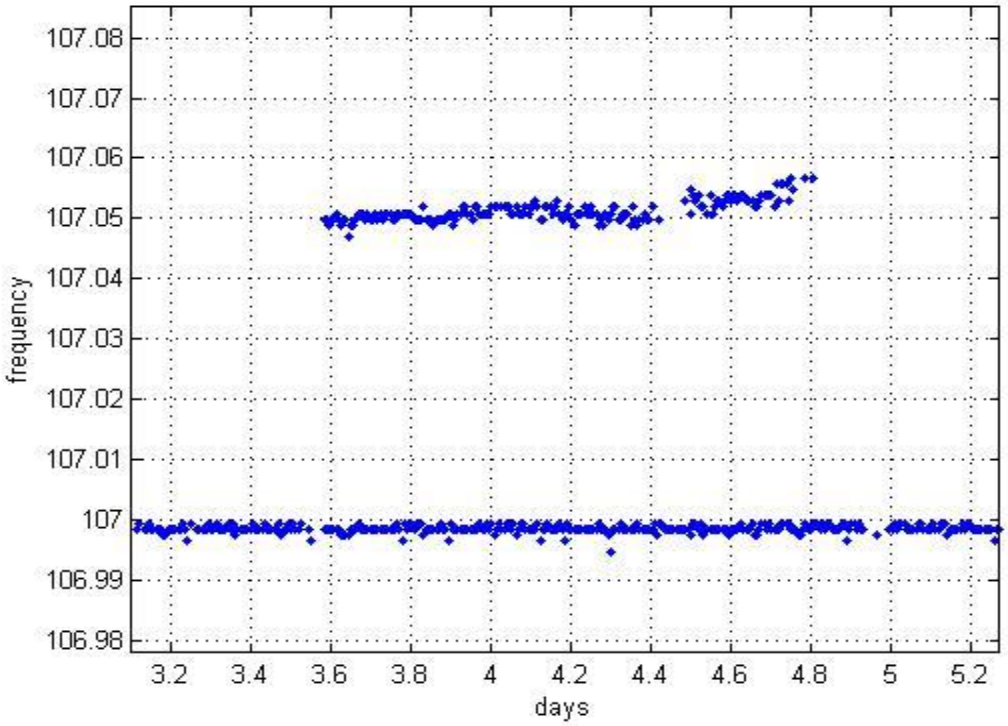
>> [t f a cr d]=read_logfev

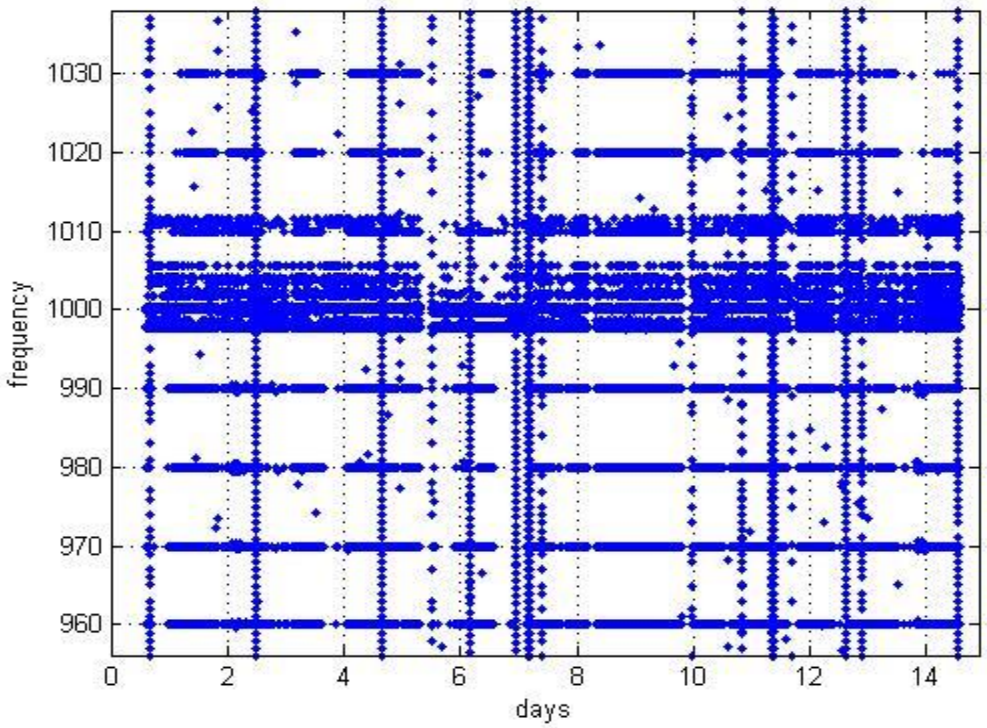
we obtain the 379960 frequency events in the log. Here is the plot

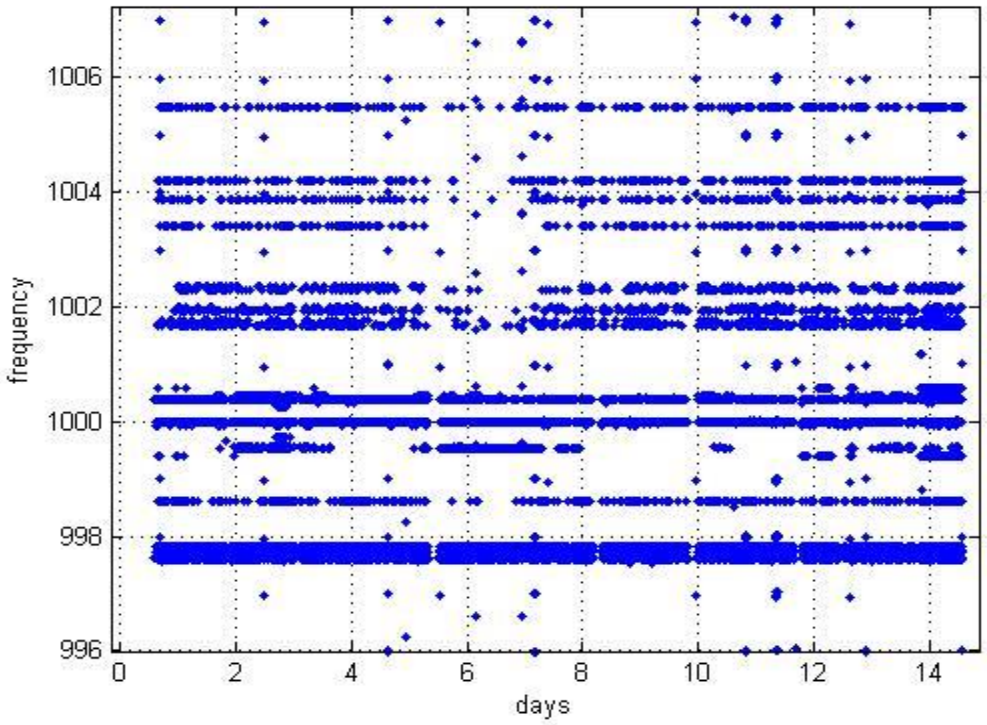


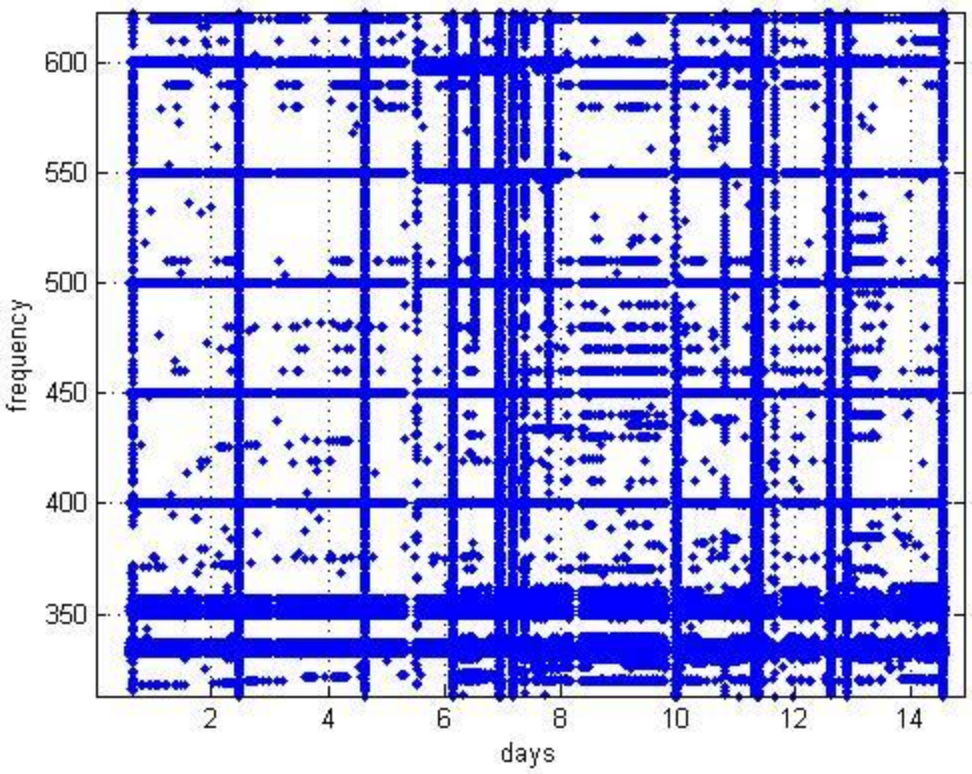
and here are some zooms:

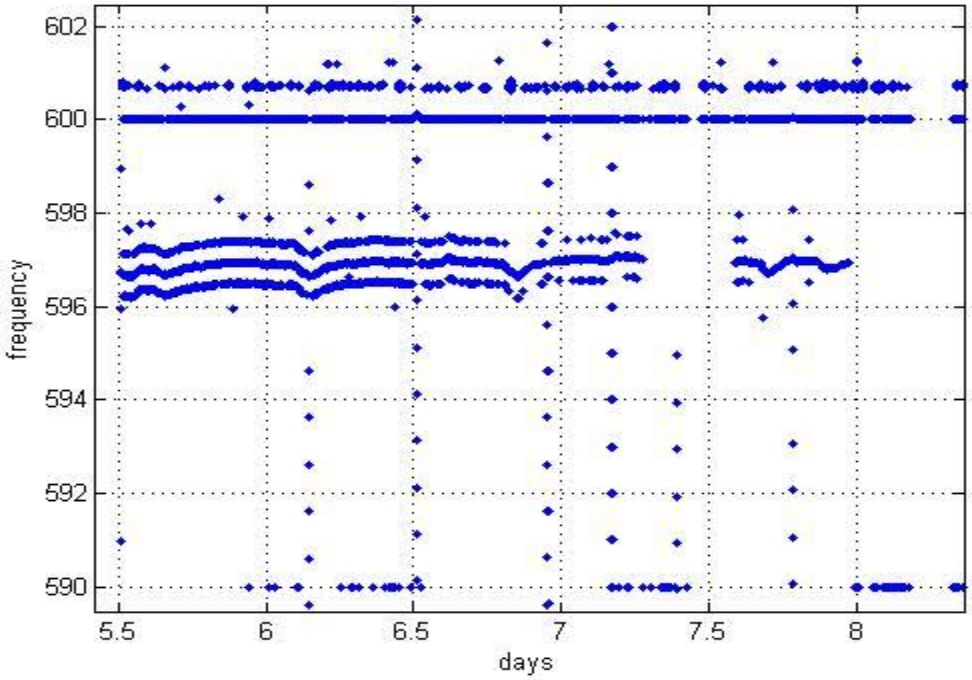


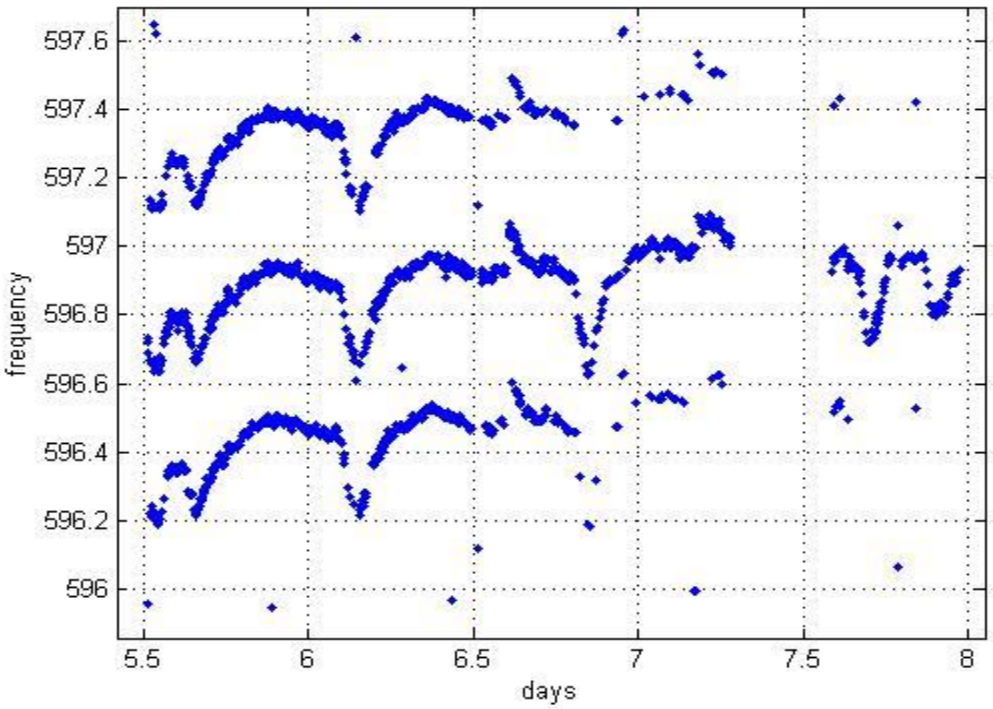

107.08
107.07
107.06
107.05
107.04
107.03
107.02
107.01
107
106.99
106.98
frequency
3.2
3.4
3.6
3.8
4
4.2
4.4
4.6
4.8
5
5.2
days

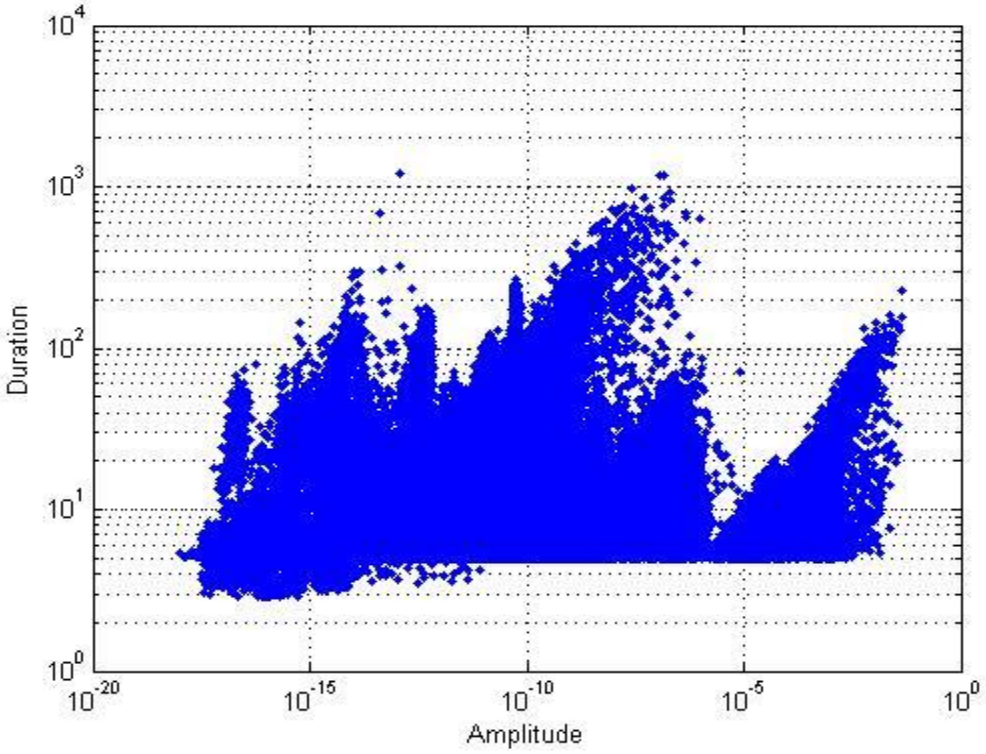

frequency
1030
1020
1010
1000
990
980
970
960
0
2
4
6
8
10
12
14
days


frequency
1006
1004
1002
1000
998
996
0
2
4
6
8
10
12
14
days


600
550
500
450
400
350
frequency
2
4
6
8
10
12
14
days


602
600
598
596
594
592
590
frequency
5.5
6
6.5
7
7.5
8
days


597.6
597.4
597.2
597
596.8
596.6
596.4
596.2
596
frequency
5.5
6
6.5
7
7.5
8
days


10^4
10^3
10^2
10^1
10^0
Duration
10^{-20}
10^{-15}
10^{-10}
10^{-5}
10^0
Amplitude

The PSS databases and data analysis organization

General structure of PSS databases

The general organization of the PSS databases, i.e. the folder tree, is the following:

- First level: antennas and general metadata (general, server and analysis)
- Second level: data categories and antenna metadata. Data categories are:
  - **sd** – (sampled data) h-reconstructed or equivalent
  - **sfdb** - sfdb data
  - **esp** - equalized spectra
  - **pm** - peak maps
  - **cand** - candidate
  - **metadata** - antenna metadata
  - **analysis** – analysis reports
- Third level (optional): different data types
- Other level: optional internal organization of sub-databases

The naming of files is such that they are alphabetically ordered for the basic key (normally time). A possible implementation is the following:

AntennaName_DataType_StartTime_Characteristics.FormatExt

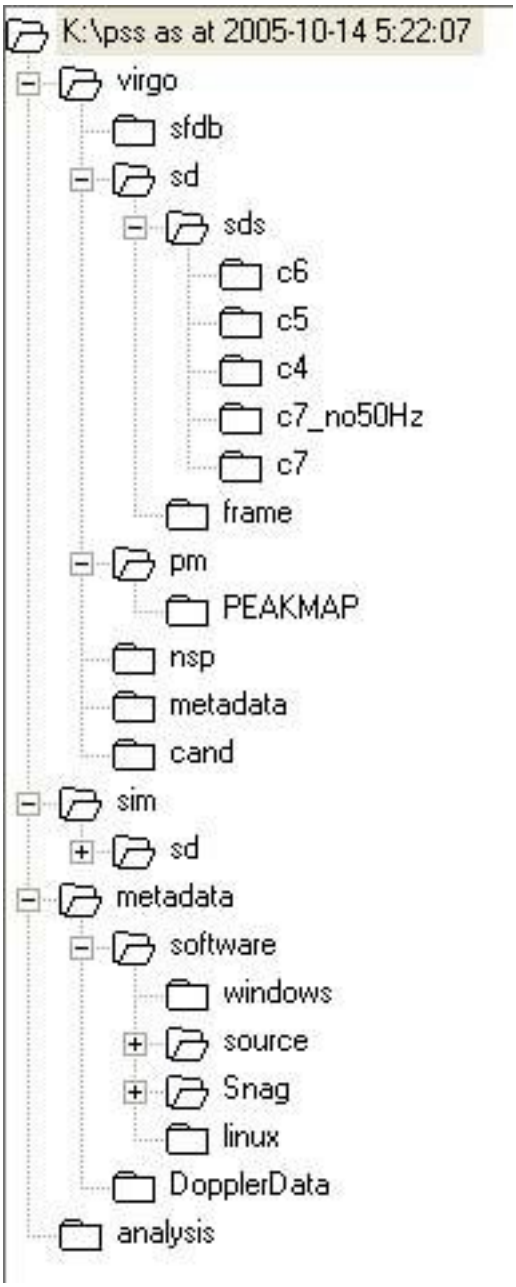
where

- **AntennaName**, for example:
  - Vir
  - Nau
  - Exp
- **DataType**, for example:
  - raw
  - hrec

    - sfdb
    - esp
    - pm

- **StartTime**, in the format **YYMMDD_hhmmss**
- **Characteristics** depends on the category
- **FormatExt** depends on the data format (frame, r87, sds,…)

The pss directory structure



The h-reconstructed database

Third level is: frame, r87, sds. Fourth level can be runs or years.

The naming is derived as easily as possible, by the original antenna name.

The sfdb database

The normalized spectra database

The peak-map database

The candidate database

See “Candidate database and coincidences”, page 87.

The coincidence database

See “Candidate database and coincidences”, page 87.

Database Metadata

Server docs

It should contain information on the available servers, how to reach them, what is supposed to contain.

Analysis docs

This should contain the analysis batch log and where the results are stored.

Antenna docs

It should contain at least:

- Antenna basic information (e.g. the position)
- Channel names
- Basic information on the runs

File System utilities

Organization of the workflow

Basic analysis periods

For short runs (up to about fifteen days), the analysis is done for each full run. This applies to the sds, sfdb and peakmap creation. The subsequent analysis (Hough map, candidates, coincidences,…) could be independent of this basic division.

For longer runs the analysis is divided in segments of 10 days (decades). Each decades contains all the data contained in the original frame files starting from the 0 hour UTC of the first day to the 24 hour of the tenth day. So we act as the real run is divided in sub-runs of about ten days. The data (sds, sft, peakmaps) should be put in separated sub-folders with the name convention **deca_yyyymmdd**.
As an example, this are the first decades for the VSR1_v2:

Decade	Beginning	End
1	18-May-2007 21:02:46	28-May-2007 03:59:46
2	28-May-2007 03:59:46	07-Jun-2007 01:55:06
3	07-Jun-2007 02:48:36	16-Jun-2007 01:46:26

Initial analysis steps

hrec extraction

sds creation and reshaping

sfdb creation

peakmap creation

Main analysis

Data quality

Hough map candidates

Final analysis

Coincidence

Coherent analysis

Other tasks organization

Known pulsar investigation

Known location investigation

Appendix

Doppler effect computation

pss_astro

PSS_astro, is a C code for the computation of various astrometric quantities, coordinate transformations, evaluation of Doppler effect. It uses a JPL C code to read and manage the ephemerides file **DE405**.
It also uses **NOVAS** (Naval Observatory Vector Astrometry Subroutines), a C code, for the computation of a wide variety of common astrometric quantities.

The JPL Planetary and Lunar Ephemerides can be downloaded from the site

ftp://navigator.jpl.nasa.gov/pub/ephem/export/
by choosing the appropriate way, depending on the operating system (**/unix** is the directory for unix users and **/ascii** for non-unix users).
The instructions are written is the description file, linked at
http://ssd.jpl.nasa.gov/eph_info.html
or directly at
ftp://navigator.jpl.nasa.gov/pub/ephem/export/usrguide

Each ascii file contains 20 years of data, while each unix binary file contains 50 years of data. Anyway, we have experienced some problems with the binary UNIX files, while the ASCII files work properly even on an UNIX machine.
Then, the procedure we have used to download the ephemerides **DE405** for the years **1980-2020** is:

- download, from the directory **/ASCII,** the files: **ascp1980.405, ascp2000.405**
- download, from the directory **/FORTRAN**, the code **asc2eph.f**, which must be used to convert the ASCII files into binary files and to merge them to form a single ephemeris file.

Then :

- in **asc2eph.f,** set the NRECL parameter to 4.
- compile and link
  (g77 -c asc2eph.f g77 -o asc2eph.out binmerge.o)
- run the code, with the following syntax:
  on Unix:
  cat header.405 ascp1980.405 ascp2000.405 | ./asc2eph.out
  on windows (using command console):
  copy header.405 ascp1980.405 ascp2000.405 infile.405
- and then run asc2eph.out infile.405

This procedure produces the binary file **jpleph.**
We have renamed it to **Jpleph.405.**

Theory: Astronomical Times

A good introduction to the definitions of the Astronomical times is given here:
http://www.gb.nrao.edu/~rfisher/Ephemerides/times.html

TAI is the International Atomic Time

UTC is the Coordinated Universal Time

UTC = TAI - (number of leap seconds)

TDT is the terrestrial dynamic time. It is not yet used for planetary motions calculations, but it is only used to calculate TDB, which takes into account relativistic effects.
TDT = TAI + 32.184 = UTC + (number of leap seconds) + 32.184
it is tied to the atomic time by a constant offset of 32.184 seconds.

TDB is the Barycentric Dynamic Time
approximately:
TDB = TT + 0.001658 sin(g) + 0.000014 sin(2g) seconds
where
g = 357.53 + 0.9856003 (JD - 2451545.0) degrees
and JD is the Julian Date.
UT1 is the Universal Time, and it is a measure of the actual rotation of the Earth. Hence it is not uniform.
It is the rotation of the Earth with respect to the mean position of the Sun.
UTC is incremented by integer seconds (leap seconds) to stay within 0.7 seconds of UT1.
Then he difference between UT1 and UTC is never greater than this.
Planetary motions are computed using TDB.
UT1 should be used to evaluate
GMST, Greenwich Mean Sidereal Time
but UTC can be used as a good approximation of UT1.
In the code, we can use either UTC or UT1, by setting a
flag.
Sidereal time is the measure of the Earth's rotation with respect to distant celestial objects.

Theory: Contributions to the Doppler effect

The Doppler shift, that is the frequency *nu_doppler*, observed at the detector, for a given source whose intrinsic frequency, supposed to be constant, is *source->frequency* is mainly the result of :

1)Earth revolution around the Sun
2)Rotation
and,
1)relativistic delay (Einstein effect)
2)light deflection in the Sun's field (Shapiro effect).

To get an idea of the relative weight of these effects, we
have run the code and we have written the separate contributions.

We have used: detector Parkes,
PSR 437 (supposed to be at rest, with ra and dec given at
Epoch J2000). Their coordinates are both defined in the header file, *daspostare.h*.
Let us consider the quantity
z=(source->frequency-nu_doppler)/source->frequency

At the MJD 49353.0833 (January 1th, 1994) we get:
1)Revolution: 2.916691723 *10^(-5)
2)Rotation: -4.3508614 * 10^(-7)
3)Deinstein: -3.3540 * 10^(-10)
4)Dshapiro: -4.65 * 10^(-13)

Thus, the total value of the considered variable z is
*2.87314952 * 10^(-5)*, including Einstein and Shapiro.

We have done a (not formal) comparison of these results with C. Cutler (Potsdam AEI). The results of the comparison have been:
1)Cutler Revolution: 2.91669173 *10^(-5);
2)Cutler Rotation: -4.3508340 * 10^(-7);
3)Cutler Deinstein: -3.3439 * 10^(-10);
4)Cutler Shapiro -4.73 * 10^(-13);
Cutler total value is *2.87315000 * 10^(-5)*.

We have indicated in red those numbers that are different from Cutler's.

Hence the difference between our result and Cutler result is, for the considered variable z, 4.*8 10^(-12)*.

We recall that this comparison has been done not formally,
on August 2000. In particular, we don' t know if Cutler now is

still getting these numbers.

We have done this, and other comparisons using TEMPO.

Programming tips

Windows FrameLib

[FrameLib 6r18] To construct the FrameLib.lib, we have to comment the line

```
#include <unistd.h>
```

in **FrIO.c** . The functions **dup, open, close, write, read, lseek** are not defined. They are used if it is not defined **FRIOCFILE**.

Non standard file formats

SFDB

FORMAT of the SFDB files

Format of the SFDB files:

files are binary, in blocks. Each block has:

1. header;
2. Averages of the short power spectra (with time) in units EINSTEIN/Hz
3. AR short power spectra (obtianed with a subsampling factor which is written in the header). They contain the amplitude, which has to be squared to get the very short power spectrum. Units EINSTEIN/Sqrt(Hz);
4. FFTs (real and imag part) in units EINSTEIN/Sqrt(Hz).

The header contains all the relevant information which regards the detector and information on how the Data-Base has been done. Parameters written in the header are put in the structure **HEADER_PARAM,** which is defined in pss_sfdb.h.

To read the files one has to read, in order:

- **HEADER**
- **Averages of the short power spectra (with time)**
- **AR short power spectrum**
- **FFTs (real and imaginary part)**

Open the file:

```
OUTH1=fopen(filename,"r");
```

Read the header_param :

```
fread((void*)&header_param->endian, sizeof(double),1,OUTH1);
fread((void*)&header_param->detector, sizeof(int),1,OUTH1);
fread((void*)&header_param->gps_sec, sizeof(int),1,OUTH1);
fread((void*)&header_param->gps_nsec, sizeof(int),1,OUTH1);
fread((void*)&header_param->tbase, sizeof(double),1,OUTH1);
fread((void*)&header_param->firstfreqindex, sizeof(in1,OUTH1);
fread((void*)&header_param->nsamples, sizeof(int),1,OUTH1);
fread((void*)&header_param->red, sizeof(int),1,OUTH1);
fread((void*)&header_param->typ, sizeof(int),1,OUTH1);
fread((void*)&header_param->n_flag, sizeof(int),1,OUTH1);
fread((void*)&header_param->einstein, sizeof(float),1,OUTH1
fread((void*)&header_param->mjdtime, sizeof(double),1,OUTH1);
fread((void*)&header_param->nfft, sizeof(int),1,OUTH1);
fread((void*)&header_param->wink, sizeof(int),1,OUTH1);
fread((void*)&header_param->normd, sizeof(int),1,OUTH1);
fread((void*)&header_param->normw, sizeof(int),1,OUTH1);
fread((void*)&header_param->frinit, sizeof(double),1,OUTH1);
fread((void*)&header_param->tsamplu, sizeof(double),1,OUTH1);
fread((void*)&header_param->deltanu, sizeof(double),1,OUTH1);
fread((void*)&header_param->vx_eq, sizeof(double,1,OUTH1);
fread((void*)&header_param->vy_eq, sizeof(double),1,OUTH1);
fread((void*)&header_param->vz_eq, sizeof(double),1,OUTH1);
fread((void*)&header_param->spare1, sizeof(double),1,OUTH1);
fread((void*)&header_param->spare2, sizeof(double),1,OUTH1);
fread((void*)&header_param->px_eq, sizeof(double),1,OUTH1);
fread((void*)&header_param->py_eq, sizeof(double),1,OUTH1);
fread((void*)&header_param->pz_eq, sizeof(double),1,OUTH1);
fread((void*)&header_param->n_zeroes, sizeof(int),1,OUTH1);
fread((void*)&header_param->sat_howmany, sizeof(double),1,OUTH1);
fread((void*)&header_param->spare1, sizeof(double),1,OUTH1);
fread((void*)&header_param->spare2, sizeof(double),1,OUTH1);
fread((void*)&header_param->spare3, sizeof(double),1,OUTH1);
fread((void*)&header_param->spare4, sizeof(float),1,OUTH1);
fread((void*)&header_param->spare5, sizeof(float),1,OUTH1);
fread((void*)&header_param->spare6, sizeof(float),1,OUTH1);
fread((void*)&header_param->spare7, sizeof(int),1,OUTH1);
fread((void*)&header_param->spare8, sizeof(int),1,OUTH1);
fread((void*)&header_param->spare9, sizeof(int),1,OUTH1);
```

Derive, from the header, parameters to read next data:

```
howmany=header_param->nsamples; //number of samples stored
howmany2=howmany*2;      // dimension of the total FFT
```

```
dx=header_param->deltanu; //frequency resolution
lenps= (int) howmany2/(header_param->red);
```

Read the averages of spectra with time

```
ps=(float *)malloc((size_t) (header_param->red)*sizeof(float));
for(ii=0;ii<header_param->red;ii++){
        errorcode=fread((void*)&rpw, sizeof(float),1,OUTH1);
         if (errorcode!=1) {
            printf("Error in reading power ps data into SFT file! %d \n",ii);
            return errorcode;
       }
      ps[ii]=rpw;
   }
 free(ps);
```

Read the AR subsampled short power spectrum

```
ps_short=(float *)malloc((size_t) (lenps/2)*sizeof(float));
for(ii=0; ii<lenps/2; ii++){
     errorcode=fread((void*)&rpw, sizeof(float),1,OUTH1);
       if (errorcode!=1) {
          printf("Error in reading  short FFTs  into SFT file! %d \n",ii);
          return errorcode;
       }
    ps_short[ii]=rpw;
  }
free(ps_short);
```

Note:
the vectors ps and ps_short need to be defined only if one needs to use them.

Read the FFTs data

```
 kk=0;
norm=pow(header_param->normd,2)*pow(header_param->normw,2);

 for(ii=0;ii< 2*howmany; ii+=2){
     errorcode=fread((void*)&rpw, sizeof(float),1,OUTH1);
```

```
    if (errorcode!=1) {
        printf("Error in reading real data into SFT file! %d \n",ii);
        return errorcode;
    }
    errorcode=fread((void*)&ipw, sizeof(float),1,OUTH1);
    if (errorcode!=1) {
        printf("Error in reading imag data into SFT file! %d \n",ii);
        return errorcode;
    }

  freq=(float)(header_param->firstfreqindex+kk)*1.0/header_param->tbase;
   sden=(rpw*rpw+ipw*ipw)*norm;
    kk++;
}
```

Note:
header_param->normd is the normalization from FFT to spectra.
header_param->normw is the normalization for the window.
header_param->tbase is the duration in seconds of 1 FFT

Peak maps

p05

This is a non-standard format for the peak maps. It is translated in standard **vbl** format with **piapeak2vbl**.
These files contain 3 arrays: the bins, the equalized values and the mean value of the spectrum. The vbl files only the bins and values.

```
/***********Program to produce the peak map from the SFDB
files**************/
/***********Author:   Pia************************/
/***********Last version 23 February 2005*****************/


#include<stdio.h>
#include<math.h>
#include<string.h>
#include<stdlib.h>


/****** PSS libraries***************/
```

```
#include "../pss/PSS_lib/pss_math.h"
#include "../pss/PSS_lib/pss_serv.h"
#include "../pss/PSS_lib/pss_snag.h"
#include "../pss/PSS_lib/pss_sfc.h"
/****** Antenna libraries*************/
#include "pss_ante.h"

/****** SFDB libraries*************/
#include "pss_sfdb.h"


int main(void)
{
  int k,ii;
  int nmax;                  /*number of FFT to be read*/
  int errorcode;
  char capt_gd[12];
  GD *gd;                   /*GD with SFDB data*/
  GD *gd_short;             /*GD with the short SFDB data*/
  GD *gd_time;              /*GD with h reconstructed*/
  GD *gd_band;              /*GD with SFDB data, over a chosen sub-
bandwidth*/
  int go2time,iii,iband_extract,ipeak_extract;
  char filetime[MAXLINE+1];
  char filefreq[MAXLINE+1];
  char filepeak[MAXLINE+1];

  FILE *TIME;
  FILE *FREQUENCY;
  FILE *FINAL;
  int c;

  int ivign=0; //=1 if data are windowed before going back to the time
domain
  int istart,i_band;
  float total_band,initial_freq,band;
  int len,len4,len2,inter;
  int simulation;
  float freq_sin,amp_sin;
  double beg_mjd;
  int isubsampling;
  int write_filefreq,kkf,iif;
  double fft2spectrum;
  double phase; //phase of the sinusoidal signal added in the
simulation
  int iw;
  int fft_read;

  int nfft_tot;
  HEADER_PARAM *header_param; /*Structure with parameters which have
been  written in the sfdb file*/
  header_param=(HEADER_PARAM *)malloc(sizeof(HEADER_PARAM));
  strcpy(capt_gd,"SFDB data");
  gd=crea_gd(0.,0.,0.,capt_gd);
  gd_short=crea_gd(0.,0.,0.,capt_gd);
  printf("Number of FFTs to be read \n");
```

```
  scanf("%d",&nmax);
  printf("file with the peakmap (output) (binary)\n");
  scanf("%s",filepeak);
  PEAKMAP=fopen("appo.dat","w"); //appo file for the peakmap
  AREST=fopen("arest.dat","w");
   printf("Do you want to create the file with data in time domain ?
(1=yes)\n");
   scanf("%d",&go2time);
   if(go2time==1){
     printf("file time domain (output) (ascii)\n");
     scanf("%s",filetime);
     TIME=fopen(filetime,"w");
     printf("Time domain file opened %s \n",filetime);
   }
   printf("Do you want to create an ascii file with ALL data in
freq.domain (one 1/2 spectrum after the other)? (1=yes)\n");
   scanf("%d",&write_filefreq);
   if(write_filefreq==1){
     printf("file frequency domain (output) (ascii)\n");
     scanf("%s",filefreq);
     FREQUENCY=fopen(filefreq,"w");
     printf("Frequency domain file opened %s \n",filefreq);
   }
   istart=0;
   printf("FFT number to be written on the two test files (0=first one)
?\n");
   scanf("%d",&iw);
   for(k=0;k<nmax;k++){
     printf("FFT number (k+1) = %d \n",k+1);
     errorcode=readfilesfdb(gd,gd_short,header_param,k,iw,&fft_read);
           if (errorcode!=1){
           printf("Error in reading data into SFT file!\n");
           printf("Lette fft numero= %d  \n",k);
         if(go2time==1)printf("gd->n gd_time->n gd_time->dx %ld %ld
%f\n",gd->n,gd_time->n,gd_time->dx);
           puts("ATT: Time data do not contain the normalization from
fft^2 to spectrum, because this depends on ");
           puts("the sampling time, which is known, and the number of
data on which YOU will then to the FFT, which is unknown");
           puts("zz=fft(data).*conj(fft(data))*norm  where
norm=dt/nfft");
           if(go2time==1){
             fclose(TIME);
         }
         if(write_filefreq==1){
           fclose(FREQUENCY);
         }
         fclose(PEAKMAP);
         FINAL=fopen(filepeak,"w");    //final file for the peakmap
         PEAKMAP=fopen("appo.dat","r"); //appo file for the peakmap
         //Now write in peakmap the correct number of FFTs in the file
         nfft_tot=fft_read; //numbers of read ffts
         //fprintf(FINAL,"%d\n",nfft_tot); //se in ascii
         fwrite((void*)&nfft_tot, sizeof(int),1,FINAL); ///per
Cristiano: in binario
         while((c=getc(PEAKMAP)) !=EOF)putc(c,FINAL);
```

```
          fclose(PEAKMAP);
          fclose(FINAL);
          fclose(AREST);
            return errorcode;
       }
        fft2spectrum=sqrt((double) header_param-
>tsamplu/(2.0*header_param->nsamples));//to remove the normalization in
noise spectral density

//which depends on the sampling time and on the number

//of data on which the FFt is done. Both these parameters

//will change
       printf("fft2spectrum= %f\n",fft2spectrum);
       if(k==0){
       beg_mjd=REFERENCE_MJD;
         printf("First file mjdtime, gps time (s and ns) %15.10f %d
%d\n",header_param->mjdtime,header_param->gps_sec,header_param-
>gps_nsec);
        total_band=gd->dx*gd->n/2; //the data are Real and Imag, so
there is a factor 2
        printf("Initial frequency of the data - Bandwidth (positive
only)- total length %f %f %ld\n",gd->ini,total_band,gd->n);
       if(header_param->detector==0)printf("Minus mode, plus mode,
calibration freq %f %f %f\n",header_param->freqm,header_param-
>freqp,header_param->frcal);
       printf("Do you want to ADD sinusoidal signals ? (1=yes)\n");
       scanf("%d",&simulation);
       if(simulation==1){
       printf("Frequency, Amplitude (times EINSTEIN) \n");
       scanf("%f %f",&freq_sin,&amp_sin);
       }
       printf("Do you want to extract a bandwidth ? (1=yes)\n");
       scanf("%d",&iband_extract);
       if(iband_extract==1){
       if(header_param->detector==0)printf("Minus mode, plus mode,
calibration freq %f %f %f\n",header_param->freqm,header_param-
>freqp,header_param->frcal);
       printf("Initial frequency, bandwidth (positive band only)?\n");
       scanf("%f %f",&initial_freq,&band);
       gd_band=crea_gd(gd->n,(double) initial_freq,gd->dx,capt_gd);
       }
       if(header_param->detector>=1&&iband_extract==1){ //only for itf,
can be generalized to bars
       printf("Peakmap only on the sub-bandwidth ? (1=yes;0= on the
whole bandwidth)\n");
       scanf("%d",&ipeak_extract);
       }
       }

     if(simulation==1){
       add_sinusoids(gd,header_param,freq_sin,amp_sin,beg_mjd,&phase);
       if(header_param->typ!=2){
       beg_mjd=header_param->mjdtime+(header_param-
>tsamplu*(2*header_param->nsamples)/day2sec); //new start time to
```

```
evaluate the beginning phase
       }
       if(header_param->typ==2){
       beg_mjd=header_param->mjdtime+(header_param-
>tsamplu*(header_param->nsamples)/day2sec); //new start time to
evaluate the beginning phase
       }
     }
     if(iband_extract==1)printf("**initial freq, gd_band->dx= %f
%f\n",initial_freq,gd_band->dx);
     if(iband_extract==1)gd_band->ini=(double) initial_freq;
     if(iband_extract==1)i_band=band_extract(gd,gd_band,band);

     /*Creation of the peak map*/
      if(ipeak_extract==1)peakmap_from_ar(gd_band,header_param);
      if(ipeak_extract!=1)peakmap_from_ar(gd,header_param);
     //peakmap(gd,gd_short,header_param);
     /*end of the creation of the peak map*/
     /*Write, if required, the frequency domain file: */
     if(write_filefreq==1){
       if(iband_extract==1){
       kkf=0;
       for(iif=0;iif<gd_band->n;iif+=2){
         fprintf(FREQUENCY,"%f %d %f %f \n",header_param-
>mjdtime,kkf,gd_band->ini+kkf*gd_band->dx,gd_band->y[iif]*gd_band-
>y[iif]+gd_band->y[iif+1]*gd_band->y[iif+1]);
         kkf++;}
       }
       if(iband_extract!=1){
       kkf=0;
       for(iif=0;iif<gd->n;iif+=2){
         fprintf(FREQUENCY,"%f %d %f %f \n",header_param-
>mjdtime,kkf,gd->ini+kkf*gd->dx,gd->y[iif]*gd->y[iif]+gd->y[iif+1]*gd-
>y[iif+1]);
         kkf++;}
       }

     }
     if(go2time==1&&k==0)strcpy(capt_gd,"h reconstructed");
     if(iband_extract==1){
       if(go2time==1&&k==0)gd_time=crea_gd(gd_band->n,0.,gd_band-
>dx,capt_gd);
     }
      if(iband_extract!=1){
       if(go2time==1&&k==0)gd_time=crea_gd(gd->n,0.,gd->dx,capt_gd);
     }
      if(go2time==1){
       puts("Copy from gd or gd_band to gd_time and call gdfreq2time.
If subsampled data have to be divided by isubsampling");
       if(iband_extract==1){
       printf("gd_band->n gd_time->n  %ld %ld \n",gd_band->n,gd_time-
>n);
       isubsampling=gd->n/gd_band->n;
       for(ii=0;ii<gd_band->n;ii++)gd_time->y[ii]=gd_band-
>y[ii]/(isubsampling);
       gd_time->dx=gd_band->dx; //the function gdfreq2time then
```

```
evaluates the proper dx
       }
       if(iband_extract!=1){
       printf("gd->n gd_time->n %ld %ld \n",gd->n,gd_time->n);
       for(ii=0;ii<gd->n;ii++)gd_time->y[ii]=gd->y[ii];
        gd_time->dx=gd->dx; //the function gdfreq2time then evaluates
the proper dx
       }
       iii=gdfreq2time(gd_time,header_param,ivign);
       if(k==0){
       len=gd_time->n;
       len4=len/4;
       len2=len/2;
       inter=0;
       if(header_param->typ==2)inter=1; //data overlapped by the half
       }
       /*Remove window, if needed*/
       if(header_param->wink>0){
       wingd2gd(gd_time,header_param->wink);
       }
       printf("FFT number k, gd_time->dx, header_param->typ: %d %f %d
\n",k,gd_time->dx,header_param->typ);
       if(k==0){
       //write some information on the file at the beginning:
       fprintf(TIME,"%s %s %s %s %s \n","%", "Beginning mjd days;",
"Gps s;", "Gps ns;", "Sampling time s.");
       fprintf(TIME,"%s %s %s %s %s %s \n","%", "Beginning freq;",
"Half band;", "Samples in one stretch;","Subsampling;","2 if data were
overlapped");
       fprintf(TIME,"%s %15.10f %d %d %f\n","%",header_param-
>mjdtime,header_param->gps_sec,header_param->gps_nsec,gd_time->dx);
       if(iband_extract!=1)fprintf(TIME,"%s %f %f %ld %ld %d\n","%",gd-
>ini,total_band,gd->n,gd->n/gd->n,header_param->typ);
       if(iband_extract==1)fprintf(TIME,"%s %f %f %ld %ld
%d\n","%",gd_band->ini,gd_band->n*gd_band->dx/2.0,gd_band->n,gd-
>n/gd_band->n,header_param->typ);
       //for(ii=0;ii<(len-inter*len4);ii++)fprintf(TIME,"%d %f %f
\n",ii+istart,(ii+istart)*gd_time->dx,gd_time->y[ii]);
        for(ii=0;ii<(len-inter*len4);ii++)fprintf(TIME,"%15.10f %f
\n",(header_param->mjdtime+ii*gd_time->dx/day2sec),gd_time-
>y[ii]/fft2spectrum);
       }
       if(k!=0){
       //for(ii=inter*len4;ii<(len-inter*len4);ii++)fprintf(TIME,"%d %f
%f \n",ii+istart,(ii+istart)*gd_time->dx,gd_time->y[ii]);
       for(ii=inter*len4;ii<(len-inter*len4);ii++)fprintf(TIME,"%15.10f
%f \n",(header_param->mjdtime+ii*gd_time->dx/day2sec),gd_time-
>y[ii]/fft2spectrum);

       }
       istart+=len-inter*len2; //in the first FFT, written 3/4 len
data. In the others, written len/2 data
     }

   }
   if(go2time==1)printf("gd->n gd_time->n gd_time->dx %ld %ld %f\n",gd-
```

```
>n,gd_time->n,gd_time->dx);
   puts("ATT: Time data do not contain the normalization from fft^2 to
spectrum, because this depends on ");
   puts("the sampling time, which is known, and the number of data on
which YOU will then to the FFT, which is unknown");
   puts("zz=fft(data).*conj(fft(data))*norm  where norm=dt/nfft");
      fclose(OUTH1);
   if(go2time==1){
      fclose(TIME);
   }
 if(write_filefreq==1){
      fclose(FREQUENCY);
   }
   fclose(PEAKMAP);
  FINAL=fopen(filepeak,"w");    //final file for the peakmap
  PEAKMAP=fopen("appo.dat","r"); //appo file for the peakmap
  //Now write in peakmap the correct number of FFTs in the file
  nfft_tot=fft_read; //last fft which has been read
  //fprintf(FINAL,"%d\n",nfft_tot); //se in ascii
  fwrite((void*)&nfft_tot, sizeof(int),1,FINAL); ///per Cristiano: in
binario
  while((c=getc(PEAKMAP)) !=EOF)putc(c,FINAL);
  fclose(PEAKMAP);
  fclose(FINAL);
  fclose(AREST);
  return errorcode;
}
```

p08

It is translated to vbl format by p082vbl, or with the pss_batch_diary with the script

```
cd y:\pss\virgo\pm\VSR1-v2;

conv_p08_conc('','list.txt');
```

Here is the format.

```
% p08 format:
%
%     Header
% nfft      int32
% sfr       double (sampling frequency)
% lfft2     int32 (original length of fft divided by 2)
% inifr     double
%
%   Block header
% mjd       double
% npeak     int32
% velx      double (AU/day)
% vely      double (AU/day)
% velz      double (AU/day)
%
%   Short spectrum (in Einstein^2)
% spini     double
% spdf      double
% splen     int32
% sp        float (splen values)
%
%     Data (npeak times)
% bin       int32
% ratio     float
% xamed     float (mean of H)
```

p09

It is translated to vbl format by p092vbl or p092vbl_3 or with the pss_batch_diary with the script

```
cd y:\pss\virgo\pm\VSR1-v2;

conv_p09_conc('','list.txt');    or  conv_p09_conc_3('','list.txt');
```

Here is the format.

```
% p09 format:
%
%     Header
% nfft      int32
% sfr       double (sampling frequency)
% lfft2     int32 (original length of fft divided by 2)
% inifr     double
%
%   Block header
% mjd       double
% npeak     int32
% velx      double (v/c)
% vely      double (v/c)
% velz      double (v/c)
% posx      double (x/c)
% posy      double (y/c)
% posz      double (z/c)
%
%   Short spectrum (in Einstein^2)
% spini     double
% spdf      double
% splen     int32
% sp        float (splen values)
%
%     Data (npeak times)
% bin       int32
% ratio     float
% xamed     float (mean of H)
```

Standard Reports

Here are the standard reports for the pss data analysis.
There are also automatic reports

General

In Matlab the submission of batch procedures should be carried out by the use of the function

pss_batch_diary :

```
pss_batch_diary(mscript,user,scriptin,outdir,repname)

   mscript     m-file script to be submitted
   user        user name
   scriptin    > 0 -> print script (default)
   outdir      output directory (default pssreport)
   repname     report name (without extension, default pss_batch_diary)

 Saves the previous report in .old and updates the .rep file.
 Check and possibly edit the rep file !
```

It records the operation on a file. Example of a record:

```
START convert_peakfiles1  at 21-Aug-2006 18:14:37 by sf

% convert_peakfiles1

piapeak2vbl(4000/4194304,4194304,'peak100sfakeC7.p05','peak100sfakeC7.vbl')
piapeak2vbl(4000/4194304,4194304,'peak100fakeC7.dat','peak100fakeC7.vbl')

STOP  at  21-Aug-2006 21:33:56

----------------------------------------
```

There is another procedure that is useful for documenting interactive (and also batch) work with Matlab, that uses the Matlab Diary. It saves all the inputs and outputs of the Matlab session:

snag_diary :

```
  out=snag_diary(onoff,filnam)

or simply  snag_diary

   onoff     1 or 0 to turn on or off (if different or absent, toggles)
   filnam    filname (default diary_xxxxx in the snagout directory)
```

There is also an automatic Snag data analysis report creator function:

snag_pub

```
   dir=snag_pub(mfile,typ,outputdir_or_options)

mfile      the m-file to publish
typ        format ('doc','html','latex','ppt','xml')
outputdir_or_options  in case of options, the structure with elements:
    .format
    .outputDir   (should end with '\'; default tmp)
    .showCode    true or false
    .imageFormat

dir        output directory
```

It uses the Matlab **publish** function.

Data preparation

Candidates

Coincidences

Issues

On particular problems.

Matlab procedures (résumé)

Batch procedures

These are templates of batch Matlab procedures, to be edited.

- **do_base_run_sp** creates a "standard" spectrum from sds data
- **two_run_sensitivity** computes the sensitivity of coincidences of two runs. Some coefficients computed with pss_run_basic_analysis.xls
- **save_pia_hist** equalized spectra peak histogram
- **search_10Hz_peaks_with_ef** search 10Hz peak with epoch folding
- **convert_peakfiles** converts peak files with piapeak2vbl
- **candidate_coinc_1** single file candidate analysis
- **crea_lintfmap** driver of crea_linpm (linear peak maps)
- **clean_conv_peakfile** "cleans" p05 peak files using vbl files
- **aa_analysis** anti-aliasing analysis
- **big_coin** does big coincidence jobs
- **merge_coin** merge coincidence matrices

Preparation procedures

Check procedures

Analysis procedures

C procedures (résumé)

Reference

Some basic formulas

- **Limit on T_{FFT}**

$$T_{FFT}^{(\max)} = \frac{1}{\Omega_0}\sqrt{\frac{c}{2\cdot\nu_0\cdot R_0}}$$

where ν_0 is the radiation frequency and Ω_0 and R_0 are the parameters of the rotational epicycle. Here is a table of some epicycles of interest

	Period	Radius	$R_0\cdot\Omega_0^2$ *velocity*	$R_0\cdot\Omega_0^2$	Max Doppler %	Tmax a 2kHz
	s	m				
Rotation (equator)	86160	6.38E+06	4.65E+02	0.033928	3.10E-06	1.49E+03
Rotation (43° N)	86160	4.66E+06	3.40E+02	**0.024781**	2.27E-06	**1.74E+03**
Earth orbit	31557600	1.49E+11	**2.97E+04**	0.005906	**1.98E-04**	3.56E+03
Moon	2505600	4.75E+06	1.19E+01	2.99E-05	7.95E-08	5.01E+04
Jupiter	3.72E+08	7.39E+08	1.25E+01	2.10E-07	8.32E-08	5.97E+05
Saturn	9.28E+08	4.06E+08	2.75E+00	1.86E-08	1.83E-08	2.01E+06

- **Sky resolution**

$$\frac{d\nu}{d\alpha}\cdot\gamma = \frac{\nu_0\cdot\Omega_0\cdot R_0\cdot\cos\alpha}{c}\cdot\gamma = \frac{1}{2\cdot T_{FFT}}$$

$$\gamma = \frac{c}{2\cdot T_{FFT}\cdot\nu_0\cdot\Omega_0\cdot R_0\cdot\cos\alpha} = \frac{1}{N_D\cdot\cos\alpha}$$

where

$$N_D = T_{FFT} \cdot \nu_0 \cdot \frac{2 \cdot \Omega_0 \cdot R_0}{c}$$

is the number of frequency bins "covered" by the Doppler effect. and α is the angle between the radiation direction and the rotation axis of the orbital epicycle.

- **First order spin-down grid**

$$s_k^{(1)} = \frac{f_0}{\tau_{SD}} = k \cdot \Delta s^{(1)} = k \cdot \frac{\Delta \nu}{2 \cdot T_{obs}} = k \cdot \frac{1}{2 \cdot T_{obs} \cdot T_{FFT}}$$

with k from 0 to

$$N_{SD} = \frac{f_0}{\tau_{SD}^{(\min)} \cdot \Delta s^{(1)}} = \frac{2 \cdot f_0 \cdot T_{obs} \cdot T_{FFT}}{\tau_{SD}^{(\min)}}$$

defining

$$\tau_{SD} = \frac{\nu_0}{\dot{\nu}(0)} = \frac{f_0}{\dot{f}(0)}$$

the spin-down decay time.

- **Number of points in the parameter space:**

$$N_{tot} = 10^{-8} \pi \cdot \left(\frac{T_{FFT}}{\Delta t} \right)^3 \cdot \prod_j \left[\frac{T_{FFT}}{\Delta t} \left(\frac{T_{obs}}{\tau_{\min}} \right)^j \right]$$

where

- $\mathbf{\Delta t}$, the sampling time (e.g. 0.00025, 0.001, 0.004 and 0.016 s for the four bands)
- $\mathbf{T_{obs}}$, the observation time (e.g. 4 months, ~10^7 s)
- $\mathbf{T_{FFT}}$, the duration of the FFTs (e.g. ~1000, ~4000, ~8000 and 16000 s)
- $\boldsymbol{\tau_{min}}$, the minimum spin-down time (e.g. 10^4 years)

With $\tau_{\min} = 10^4 \ \ years$ and $\mathbf{T_{FFT}}$ chosen according to the standard bound, only the first order spin-down parameter should be used and we have:

$$N_{tot} = 10^{-8} \pi \cdot \left(\frac{T_{FFT}}{\Delta t} \right)^4 \cdot \frac{T_{obs}}{\tau_{\min}} = 2.64 \cdot 10^{14} \cdot \left(\frac{T_{FFT}}{4000\, s} \right)^4 \left(\frac{T_{obs}}{4\, months} \right) \left(\frac{0.001\, s}{\Delta t} \right)^4 \left(\frac{10^4\, years}{\tau_{\min}} \right)$$

Proposed parameters

Here is a summary of the proposed choices for the parameters of the search for periodic sources on the Virgo data. Two types of search are proposed here, as e.g.: one "normal", limited to the decay time of 10000 years, with computing cost of about one teraflops, with "high" sensitivity, and the other "low sensitivity", limited to the decay time of 100 years, with computing cost of about one half of the previous one. In this second search the sensitivity is about a factor 2 lower in h.

	Normal			
H [Hz$^{-1/2}$]	**1.00E-22**			
T_{obs} [s]	**10368000**	**months:**	**4**	
τ_{min} [s]	**3.16E+11**	**years:**	**10000**	
	Bands			
Δt [s]	0.00025	0.001	0.004	0.016
ν_{max} [Hz]	2000	500	125	31.25
T_{fft} [s]	1000	4000	8000	16000
L_{fft}	4.00E+06	4.00E+06	2.00E+06	1.00E+06
N_{fft}	1.04E+04	2.59E+03	1.30E+03	6.48E+02
N_{tot}	**2.64E+14**	**2.64E+14**	**1.65E+13**	**1.03E+12**
$N_{bas.op.}$	2.28E+17	5.71E+16	1.78E+15	5.57E+13
Gflops	8.81E+02	2.20E+02	6.88E+00	2.15E-01
Gflops tot	**1.11E+03**			
$h^{(HS)}_{SNR=1}$	**4.43E-25**	**3.13E-25**	**2.64E-25**	**2.22E-25**
Second step factor	64			
$N^{(II\ step)}_{tot}$	4.43E+21	4.43E+21	2.77E+20	1.73E+19

	Low sensitivity			
10368000	**months:**	**4**	
3.16E+09	**years:**	**100**	
	Bands			
0.00025	0.001	0.004	0.016
2000	500	125	31.25
100	400	800	1600
4.00E+05	4.00E+05	2.00E+05	1.00E+05
1.04E+05	2.59E+04	1.30E+04	6.48E+03
1.14E+13	**1.14E+13**	**3.57E+11**	**1.11E+10**
9.86E+16	2.46E+16	3.85E+14	6.02E+12
3.80E+02	9.51E+01	1.49E+00	2.32E-02
4.77E+02			
7.88E-25	**5.57E-25**	**4.69E-25**	**3.94E-25**
64			
4.43E+17	4.43E+17	2.77E+16	1.73E+15

Papers and tutorials